MPS.6-81-221

MATERIALS EXPERIMENT CARRIER CONCEPTS DEFINITION STUDY PART 2

VOLUME I

EXECUTIVE SUMMARY

TRW CONTRACT NO. NAS8-33688
17 DECEMBER 1981

PREPARED FOR

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

GEORGE C. MARSHALL SPACE FLIGHT CENTER
ALABAMA 35812

TRW
DEFENSE AND SPACE SYSTEMS GROUP
ATTACHED SHUTTLE PAYLOADS ORGANIZATION
ONE SPACE PARK • REDONDO BEACH • CALIFORNIA 90278

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1. SP81-MSFC-2535, Summary Report, "System Requirements For Baseline Materials Processing in Space Payloads." Teledyne Brown Engineering, June 1981

2. MPS.6-81-135, "Integrated Requirements for MEC Payloads," TRW, 1 August 1981

3. PM-001, "25 kW Power System Reference Concept (Preliminary)," NASA-MSFC, Program Development, Preliminary Design Office, September 1979

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7. MPS.6-80-288, "Materials Experiment Carrier Concepts Definition Study (Part 1), Volume IV - MEC Interface Requirements," TRW, October 1980

8. MPS.6-80-289, "Materials Experiment Carrier Concepts Definition Study (Part 1), Volume V - MEC Systems Requirements," TRW , November 1980

9. "Advanced MEA Study," A Conceptual Design and Analysis Study, NASA/MSFC, March 1981

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19. AAS Paper 80-249, "Materials Experiments Carrier - An Approach to Expanded Space Processing Capability," H.F. Meissinger, K.R. Taylor, and D.M. Waltz, October 1980

20. AIAA Conference July 18-19, 1979, "Materials Processing - A Matter of Gravity, L.K. Zoller

ABBREVIATIONS AND ACRONYMS

ACS	Attitude Control Subsystem
AFD	Aft Flight Deck
CCTV	Closed-Circuit TV
CDMS	Command and Data Management System
CDR	Critical Design Review
C.G.	Center of Gravity
C.L.	Center Line
C.M.	Center of Mass
CMG	Control Moment Gyro
CNES	National Space Research Center (France)
CPU	Central Processor Unit
EOL	End of Life
EOS	Electrophoresis Operations in Space
EPDS	Electric Power Distribution System
ESA	Eruopean Space Agency
ETR	Eastern Test Range
EVA	Extra-Vehicular Activity
FM	Factory Module (ref. to EOS)
FPM	Frame Per Minute
FZP	Float Zone Processing
g	Gravity Constant
GBC	Ground-Based Control
GFE	Government Furnished Equipment
GMT	Greenwich Mean Time
GSE	Ground Support Equipment
H/K	Housekeeping
HR	Heat Rejection
HX	Heat Exchanger
I/O	Input/Output
IOC	Initial Operational Capability
IUS	Inertial Upper Stage
JSC	Johnson Space Center
KBPS	Kilobits Per Second
KSA	K_u-Band Single Access (channel)
KSC	Kennedy Space Center
L	Length
M	Mass
MB	Megabits
MBPS	Megabits Per Second
MCC	Mission Control Center

MEA	Materials Experiment Assembly
MEC	Materials Experiment Carrier
Micro-g	Micro Gravity
MMS	Multimission Modular Spacecraft
MPS	Materials Processing in Space
MPS/SL	Materials Processing in Space/Spacelab Project
MSFC	Marshall Space Flight Center
NASA	National Aeronautics and Space Administration
O&C	Operations and Checkout
OMS	Orbital Maneuvering System
OPS	Orbiter Processing Facility
PDR	Preliminary Design Review
PI	Principal Investigator
P/L	Payload
PMS	Payload Management System
PPF	Payload Processing Facility
POCC	Payload Operations Control Center
PRR	Preliminary Requirements Review
PS	Power System (now Space Platform)
RAM	Read-and-Write (Random Access) Memory
RAU	Remote Acquisition Unit
RIU	Remote Interface Unit
RM	Replacement Module (ref. to EOS)
RMS	Remote Manipulator System
ROM	Read-Only Memory
SASP	Science and Applications Space Platform
SES	Solidification Experiment System
SL	Spacelab
SM	Support Module
SMA	S-Band Multiple Access (channel)
SP	Space Platform (formerly Power System)
SPCC	Space Platform Control Center
S/S	Subsystem
SSA	Service Support Assembly
STS	Space Transportation System
T	Temperature
TCS	Thermal Control System
TDRS	Tracking and Data Relay Satellite
TDRSS	Tracking and Data Relay Satellite System
T/M	Telemetry
TMS	Teleoperator Maneuvering System
TV	Television
VAB	Vehicle Assembly Building
VAFB	Vandenberg Air Force Base
VCG	Vapor Crystal Growth
VPF	Vertical Processing Facility
W	Weight
WTR	Western Test Range

1.0 INTRODUCTION

The Materials Experiment Carrier (MEC) is an optimized carrier for near-term and advanced Materials Processing in Space (MPS) research and commercial payloads. When coupled with the Space Platform (SP), the MEC can provide the extended-duration, high-power and low-acceleration environment the MPS payload typically requires.

The MPS program is conducting a systematic research program on the effects of weightlessness on technologically important processes ranging from metallurgy to biology. Research investigation of these processes typically requires high-power, long-duration experiments. In addition multiple experiment runs are required to fully isolate, characterize, and exploit the effect of weightlessness on these processes. The objective of the MEC project is to provide a system that will accommodate MPS requirements in a feasible, low-cost manner.

This study, conducted in two parts by TRW for the NASA Marshall Space Flight Center, defined the design concepts for MEC missions starting in the late 1980's.

The Part 1 effort - October 1979 to May 1981 - concentrated on the all-up MEC configuration. Study Part 2 was performed from May through December 1981 and emphasized the concept for the initial MEC.

The basic goal of this Part 2 study was to define the lowest cost, technically reasonable first step MEC that meets the MPS program future missions objectives with minimum programmatic risks.

2.0 STUDY OBJECTIVES

The basic study goal was broken down into the following objectives:

1. Demonstrate the effectiveness of the initial MEC/Space Platform idea for:
   - Accommodating high priority, multi-discipline, R&D and commercial MPS payloads
   - Conducting MPS payload operations at affordable funding and acceptable productivity levels
2. Demonstrate that the initial MEC has the growth potential to evolve into the all-up MEC.

3.0 RELATED PROJECTS

A number of studies and projects have been completed, or are now in progress, that relate to this MEC study. Data and analytic results from the following projects were used and are referenced where appropriate:

- Space Platform
- Various elements of the Space Transportation System
- Teleoperator Maneuvering System
- TDRSS communication system
- Materials Experiment Assembly
- Various MPS payload and processor development projects
- Various Space Platform projects (such as Science and Applications Space Platform).

4.0 STUDY APPROACH

The MEC Study, Part 2, was performed against four major tasks whose logic network and work flow are shown in Figure 1. In Task 1, Configuration and Trade Studies, the configuration work from Part 1 was combined with trade studies of Part 2 to derive a selected MEC concept. By selected MEC concept, we mean that combination of an initial and an all up MEC that represents the "best" course for the MEC Project with flights starting in 1987 and continuing through a series of early to growth MEC capability additions in downstream years. Task 2, End-to-End MEC Operations featured requirements and design analysis for the subsystems, concentrating on the initial MEC and the operational requirements for both the initial and the all-up MEC.

Results of Tasks 1 and 2 were correlated into a MEC concept selection recommendation to MSFC. Based on MSFC's decision on the selected MEC concept, a design definition was performed in Task 3, Definition of the Selected Concept, to detail the configuration, subsystems, payload accommodations and mission operations of the selected initial and all-up MEC systems.

Task 4, Programmatics, was completed in two phases. Task 4a developed schedule and cost trade data to support the MEC selected concept decision; 4b pertained to constructing a MEC implementation plan and estimating the cost to develop and operate the initial MEC.

Figure 2 is a matrix showing the application of study guidelines and assumptions to Part 2 Study tasks and concepts.

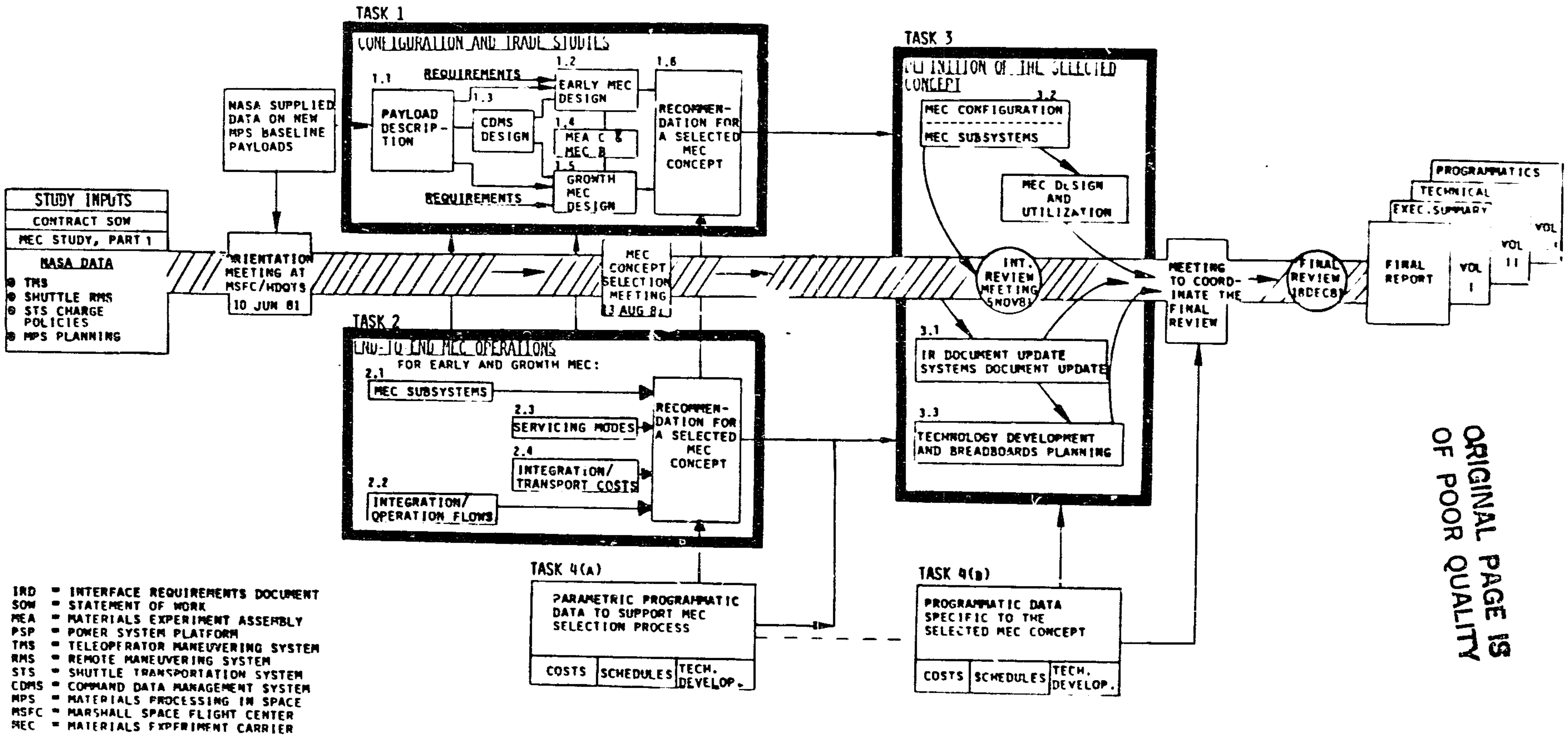

Figure 1. MEC Study, Part 2, Network of Task Flow

MEC STUDY, PART 2 GUIDELINES AND ASSUMPTIONS (Condensed from Pages 4 & 5 of RFP Work Statement)	APPLICABLE TO STUDY TASK				APPLICABLE TO MEC CONFIGURATION	
	1	2	3	4	EARLY MEC	ALL-UP MEC
A. MEC DESIGN						
1. Use MSFC data for new MPS baseline payloads	X	X			X	X
2. Design goal: orbital permanency: 90 day precursor missions, 180 days nominal	X	X	X		X	X
3. General purpose carrier, accommodate wide range of payloads	X	X	X	X		X
4. Accommodate automation techniques	X	X	X	X	X	X
5. Autonomous and automated payloads fly on MEC	X	X	X	X	X	X
B. MEC OPERATIONS						
1. MEC always flies attached to SP, use SP services	X	X	X	X	X	X
2. Shuttle is MEC delivery/return system to/from orbit	X	X	X	X	X	X
3. IOC for MEC is mid 1987, unless study shows otherwise	X	X	X	X	X	
C. COST						
1. Minimum MEC develop, operations, payload cost prime goal	X	X	X	X	X	X
2. Maximum use of existing and available systems/technology	X	X	X	X	X	
3. Consider Shuttle transportation costs and mission models in MEC design	X	X	X	X	X	X
D. SCIENCE						
Interface with MPS Science Working Groups, through COR, for data	X	X			X	X
E. INTERFACE WITH SPACE PLATFORM PROJECT (SP)						
All MEC/PSP interface documentation to go through COR	X	X	X	X	X	X

Figure 2. Study Guidelines as Related to Tasks and MEC Concepts

The MEC project is planned to take advantage of enhancements to the Space Shuttle and growth in Space Platform capabilities. The initial MEC of the late 1980's will evolve into the all-up MEC of the early 1990's. The evolution issues needing attention are shown on Figure 3.

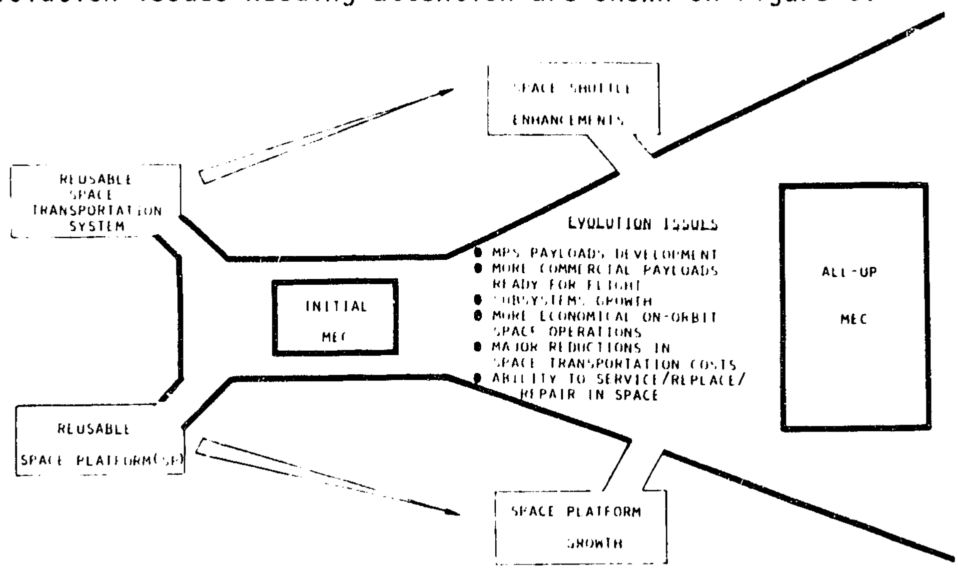

Figure 3. Materials Experiment Carrier Evolution

5.0 RESULTS

The paragraphs to follow reflect study task results. They are organized to present MEC design, mission operations, and programmatics information without making a distinction between work performed on a specific study task.

5.1 MEC PAYLOAD REQUIREMENTS

The complement of payloads for the initial MEC includes:

(1) Materials Experiment Assembly (MEA). The complement of payload facilities for MEC will be selected from those that will be available from the Shuttle based advanced MEA project. In terms of design sophistication and complexity these payload units will exceed those carried by the current MEA system.

(2) Solidification Experiment System (SES). The SES payload, intended to fly initially as a Shuttle bay pallet payload, is currently in the laboratory demonstration phase. MEC requirements were derived from information in the TRW SES Preliminary Design Review Package prepared for NASA/MSFC.

(3) Electrophoresis Operations in Space (EOS). The EOS is a commercial payload for the preparation of biological materials, in the reduced gravity environment, that have applications to pharmaceuticals.

A summary of the functions for these three baseline payloads is given below:

SES

- Isothermal or Directional Solidification Modes
- Multiple sample handling (about 15-25)
- Maximum temperature - 1200°C
- Maximum sample size 25 cm long x 1 cm diameter
- Self-contained command system
- All data downlinked
- Critical MEC parameters
  - Dimensions
  - Volume
  - Component configuration

MEA

- Number of long-term payloads (4-5)
- Multiple samples (number TBD)
- Dimensions: length no greater than 48 inches; diameter no greater than 24 inches
- Multiple payloads to operate sequentially
- Self-contained command system
- Gases required are internal to each MEA payload

Commercial Payload (EOS)

- Continuous operation
- On-orbit servicing required (6 mos.)
- Uplink commands
- Downlink data to sponsor facility
- Critical parameters
  - Diameter
  - Volume
  - Mass

The physical and electrical power/energy requirements of the baseline payloads, Figure 4, indicate that, while the three payloads impose about equal power requirements (3 to 5 kW each) on the Space Platform/MEC, the EOS is by far the largest and heaviest of the three. This introduces special payload accommodation issues into the derivation of the initial MEC concept.

PAYLOAD \ REQUIREMENTS	DIMENSIONS FEET (METERS)	VOLUME CUBIC FEET (METERS)	MASS LBS (KG)	ELECTRICAL POWER (KW)	ENERGY (KWH) (180 DAY MISSION)	THERMAL HEAT REJECTION (KW)
SES	8.5 x 4.9 x 5.9 (2.6 x 1.5 x 1.8)	245 (6.93)	2420 (1100)	4.6	13,000	4.7 0^oC INLET TEMP.
MEA	14.0 dia x 2.5 length (4.27 x .76)	577 (16.3)	4873 (2215)	3 to 5	10,800-18,000	3-5 0^oC INLET TEMP.
EOS	14.0 dia x 8 length (4.27 x 2.44)	1231 (34.8)	9988 (4540)	3.5	15,200	3.5 0^oC INLET TEMP.

Figure 4. Baseline Payload Size and Power Requirements

The integrated requirements, Figure 5, for the initial MEC were derived by summing the individual payload requirements.

- INITIAL MEC -

ITEM	VALUE	COMMENTS
PAYLOAD DIMENSIONS	Variable	Varies with specific payload. Dimensions are MEC configuration dependent.
VOLUME (PAYLOADS)	1800 ft^3	Volume is 822 ft^3 for MEA and SES.
MASS	16290 lbs	Payload mass for MEA and SES = 6290 lbs. (max)
ELECTRIC POWER (kW)	15.0	Maximum power with SES, MEA and EOS all operating at same time. Average power will be 8 to 11 kW dependent upon timeline.
ENERGY (kWH)	39000-46000	Based on nominal timelines for 180 day mission
THERMAL HEAT REJECTION (kW)	11.2-13.2 (0^oC inlet)	Minimum of 3.5 kW (EOS only).
PROCESS CONTROL	Uplink commands required	EOS and SES required capability for experiment protocol modification.
DATA ACQUISITION	12-17 kbps	Format for each experiment has not been identified. No video downlink for initial MEC.
GAS	Ar - 1 kg He - 6 kg O_2 - 29 kg	All gases are internal to the payloads.
SAMPLE NUMBER AND PROCESSING TIME	Continuous operation	Samples and sample storage are all internal to payload. Processing time for SES will be a minimum of 2000 hours. EOS is continuous operation. MEA is undefined.
VENTING	H_2O - 0.7 kg/day He - 1 kg/quench Ar, He, O_2 - TBD	Other low level venting will occur. MEA TBD.
CONTAMINATION	Vented gases and leaked materials	

Figure 5. MEC Top Level Integrated Payload Requirements

5.2 MISSION AND SYSTEM REQUIREMENTS

Principal MEC mission objectives are (a) long stay time in orbit, (b) high power level to support the complement of MEC materials processing payloads and (c) a sustained, undisturbed micro-g environment of 10^{-5}g or better.

The updated MEC system requirements (see Figure 6) partly supersede those covered in the earlier System Requirements Document (Study Part 1) dated November 1980. However, that document and the corresponding Interface Requirements Document are sources of information for defining MEC mission and system requirements in general terms.

Mission Characteristics

The projected initial flight date will be late 1987 or early 1988, keyed to the IOC of the Space Platform.

MEC shall be carried to orbit, attached to the SP and deployed into the free flying mission phase by the Shuttle Orbiter. At the end of the mission the MEC shall be retrieved by the Orbiter and returned to the ground.

During extended, all-up MEC missions the Orbiter shall revisit the SP/MEC at least once, to perform essential services such as payload exchange, processed sample exchange, or possibly replacement of defective support systems. EOS servicing requires replacement of the Resupply Module.

The same MEC vehicle shall be used repeatedly. After retrieval from orbit it shall be refurbished on the ground and/or refitted with a new payload complement and prepared for relaunch. Projected turn-around time between missions will be six or possibly eight months.

Mission durations will be 180 days for the initial MEC and possibly longer for the all-up MEC, with up to one or even two MEC launches per year, depending on mission durations and turn-around times between missions.

Payload Operation Requirements

Operation of MPS payloads on orbit will require automated sequencing of activities which typically include:

DESIGN

1. MEC WILL EVOLVE FROM INITIAL CAPABILITY (9 TO 11 KW NOMINAL, 18 KW PEAK) TO FULL ("ALL-UP") CAPABILITY (25 KW NOMINAL, 40 KW PEAK) PACED BY SP GROWTH AND MPS PAYLOADS EVOLUTION

2. PAYLOADS FOR INITIAL MEC MISSIONS WILL INCLUDE

   - ADVANCED SOLIDIFICATION EXPERIMENT SYSTEM (SES) 3-5 KW
   - UP TO 7 PAYLOAD FACILITIES, ADAPTED FROM ADVANCED MEA(1) 3-5 KW EACH
   - ELECTROPHORESIS OPERATIONS IN SPACE (EOS) 3-5 KW

3. LIMITED SP POWER CAPACITY AND ACCOMMODATION OF OTHER USERS REQUIRES TIME-SHARED MEC PAYLOAD OPERATION

4. PAYLOADS WILL OPERATE AUTONOMOUSLY, MONITORED AND CONTROLLED BY MEC CENTRAL CDMS

5. ACCESS TO PAYLOADS FOR ON-ORBIT SERVICING (P/L OR SAMPLE CHANGEOUT) WILL BE REQUIRED ONLY ON ALL-UP MEC

6. MEC DESIGN AND OPERATION CONSTRAINED BY STS AND ASTRONAUT SAFETY REQUIREMENTS

MISSION

1. MEC/SP MISSIONS CHARACTERIZED BY

   - LONG STAY TIME IN ORBIT (180 DAYS AND LONGER)
   - HIGH POWER LEVEL TO PAYLOADS (UP TO 25 KW NOMINAL)
   - SUSTAINED, UNDISTURBED MICRO-ENVIRONMENT ($\leq 10^{-5}$g)(2)

2. SIX MONTH BASELINE MISSION DURATION CONFORMS WITH PROJECTED TWICE-A-YEAR SP REVISITS BY SHUTTLE

3. MEC IS UNCONSTRAINED AS TO ORBIT ALTITUDE AND INCLINATION, ORIENTATION AND BERTHING PORT ASSIGNMENT

4. ONLY CRITICAL MEC PROCESSES AND PROCESS PHASES REQUIRE INTERACTIVE CONTROL BY POCC, IN NEAR-REAL-TIME, VIA TDRSS/SP FORWARD AND RETURN RELAY LINKS.

5. TELEOPERATOR MANEUVERING SYSTEM (TMS) MAY BE USED IN MEC DEPLOYMENT, RETRIEVAL AND SERVICING TO REDUCE ORBITER MANEUVER REQUIREMENTS

6. MEC IS A REUSABLE, VERSATILE CARRIER OF MPS PAYLOADS

---

(1) MEA-MATERIALS EXPERIMENT ASSEMBLY, WILL FLY ORIGINALLY ON SPACE SHUTTLE AS AN ORBITER BAY PAYLOAD
(2) OCCASSIONAL MICRO-g DISTURBANCES OF ABOUT 10^{-3}g ACCEPTABLE TO SOME PAYLOADS

Figure 6. MEC System Requirements

- Sample removal from storage
- Sample insertion into processor
- Sample heating, melting, solidification, quenching or other similar physical/metallurgical processes
- Sample removal from processor and storage
- Purging of processing chamber

Other process types such as chemical and biological processing require fewer discrete steps but involve continuous treatment of liquid sample quantities with cycled variation of state parameters such as temperature, pressure, electrostatic fields etc.

Payload autonomy was emphasized. Each payload will carry its own power conditioning, control electronics, implementation, data acquisition and management, sample handling and storage, and gas/fluids.

Payload Access for Servicing On Orbit

Payloads carried in all-up MEC missions must have design and interface characteristics that are consistent with, and facilitate on-orbit servicing. Servicing operations include exchange of entire payload units or of sample magazines, within payloads, and possibly replacement of malfunctioning payload subsystems.

Interfacing System Elements

The MEC mission require the support of a number of interfacing systems in orbit or on the ground, Figure 7. Other external system elements which will indirectly interface with, and impose constraints on MEC include companion payloads carried by the Shuttle and companion payloads sharing the SP with MEC.

Space Platform (Figure 8)

1. Power
2. Heat rejection
3. Data handling/telemetry channels
4. Command channels
5. Attitude stabilization

Ground Support Equipment

1. Handling
2. Shuttle integration
3. Checkout
4. Post-foight ops

POCC Via TDRSS/SP Link

1. Command and telemetry links
2. Monitor and control experiments (including real time control, as required)

Shuttle Orbiter (Figure 9)

1. Launch
2. Deploy/retrieve (RMS)
3. Checkout
4. Power
5. Thermal protection
6. Servicing support * (RMS)
7. Safety

Orbiter Crew

1. Deploy/retrieve
2. Remote/EVA
3. On-orbit checkout
4. Servicing*

Teleoperator Maneuvering System

1. Maneuver support in SP revisits (MEC launch, retrieval, service*)
2. Remote handling of MEC or MEC payload units.

*In All-Up MEC Only

Figure 7. MEC External Interfaces

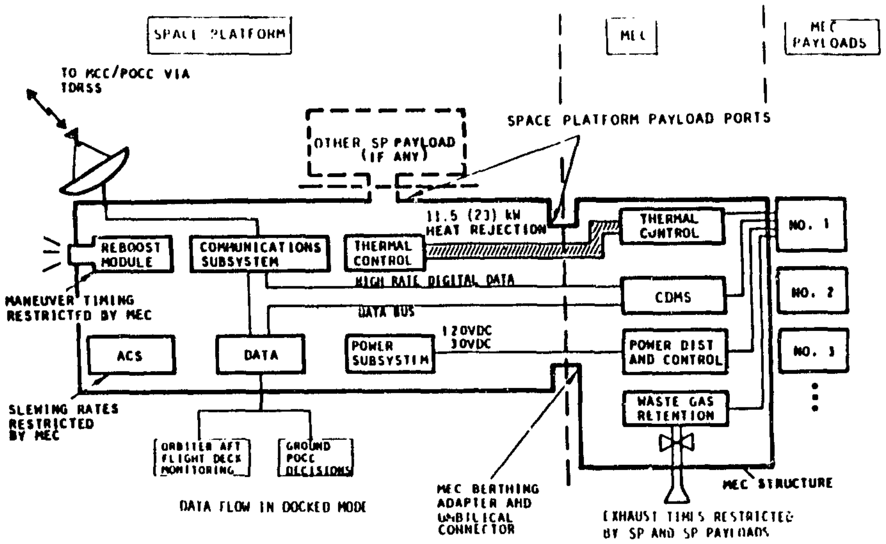

Figure 8. MEC/Space Platform and Related Interfaces

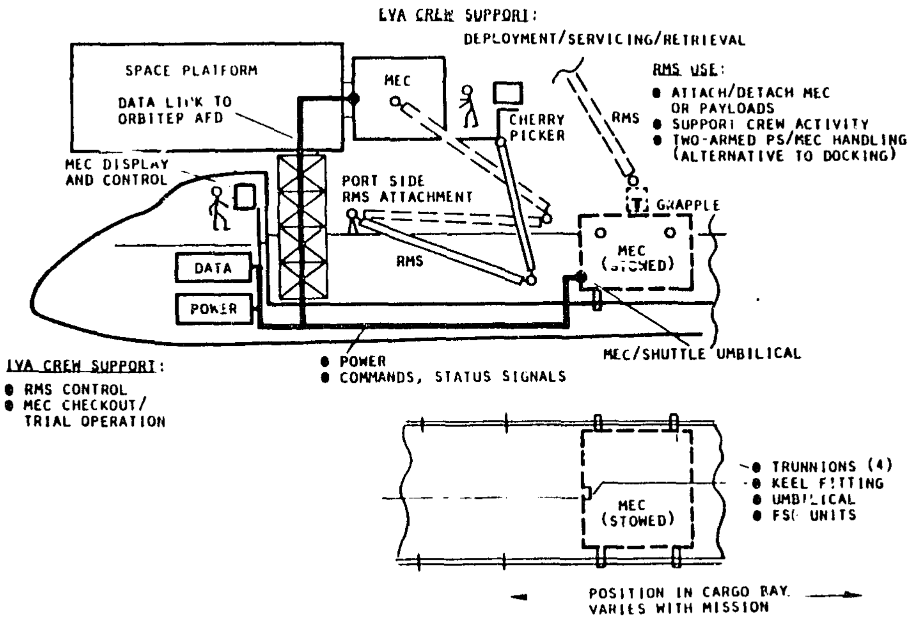

Figure 9. MEC Interfaces With Shuttle Orbiter Crew

5.3 SYSTEM DESIGN

The principal MEC configuration selection criteria listed below reflects the system and mission requirements established at the outset of the study.

1. Assurance of system safety and mission success.
2. Multiple payload accommodation as specified for initial, and all-up MEC.*
3. Low cost initial MEC by way of available structural elements, subsystem components and ground support equipment.
4. Easy growth to all-up MEC, e.g., through modular growth.
5. STS launch cost economy (weight and length).
6. Ease of payload access for on-orbit servicing for all-up MEC
7. Ease of payloads and subsystems ground integration and testing.
8. Non-interference with other Space Platform users (compact design).

The study concentrated on defining an initial MEC design concept that would meet the system requirements previously defined, carry the desired payload complement and have the capability of evolving by modular growth into the all-up MEC configuration.

Exploratory initial MEC design concepts investigated during the study primarily involved the following configuration types

1) Pallet-based configurations including the full pallet, half-pallet and combinations of pallet and other payload support structures.
2) MEA-C based configurations involving only minor changes from the MSFC spoked-disc design.
3) MEA-C based configurations involving major modifications from the support disc design.

Six examples of these MEC configuration families are illustrated in Figure 10 three of which are shown attached to the upper Space Platform payload berthing port (z-port).

Figure 11 lists principal features of the twelve initial MEC configurations investigated, with groups of four enclosed in each of the three categories indicated. *The selected initial MEC configuration, designated as concept M, is based on the MEA-C spoked disc concept with only minor changes.*

*Accommodation of EOS desirable but not mandatory. EOS may be attached directly to SP

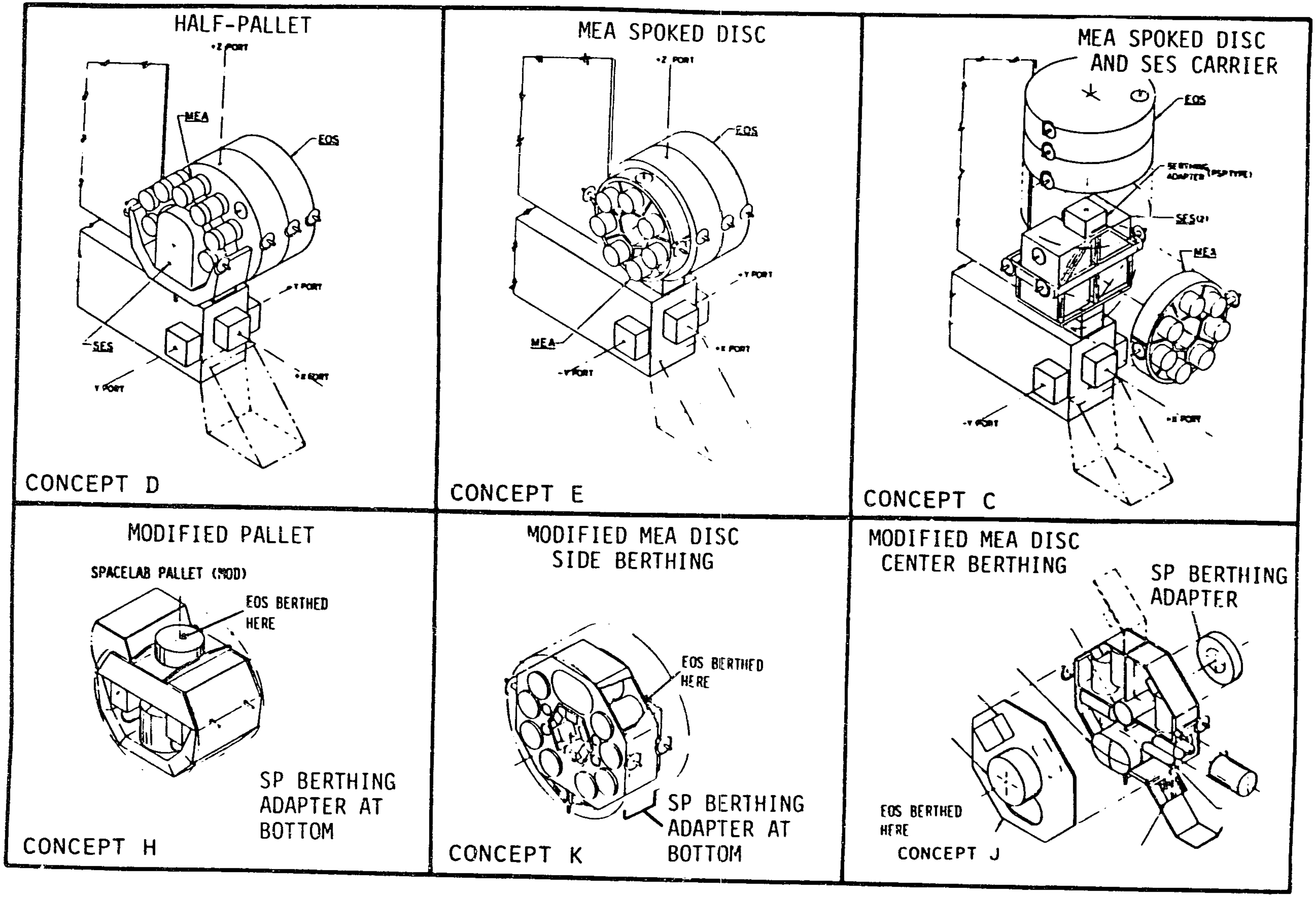

Figure 10. Some Exploratory Initial MEC Design Concepts

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CONFIGURATION TYPE	PALLET HALF-PALLET PALLET COMBINATION	MEA-C SPOKED DISC (W. MINOR CHANGES)	MEA-C SPOKED DISC (MODIFIED)
TRW DESIGN DESIGNATION	A, B, D, H	C, E, G, M	F, J, K, L
LOCATION OF S/P ADAPTER	PALLET BOTTOM (EXCEPT "B," FRONT FACE ADAPTER)	IN "M" ALONG CENTER LINE (OTHERS AT BOTTOM)	ALONG CENTER LINE (EXCEPT "K," AT BOTTOM)
MODULE GROUPING	IN LINE, EXCEPT "H" (CLUSTERED)	IN LINE, EXCEPT "G" (CLUSTERED)	IN LINE, EXCEPT "F" (CLUSTERED)
PAYLOADS ACCOMMODATED			
- MEA FACILITIES	4 TO 7	6 TO 7	7 TO 8
- SES	1 OR 2	1	1
- EOS	YES	YES	YES
PAYLOAD ATTACHMENT/ ACCESS	RACK MOUNTED	AXIAL	AXIAL OR LATERAL
GROWTH TO ALL-UP MEC INVESTIGATED*	(SEE NOTE)*	M	J, K, L
REMARKS	"A" IS POSSIBLE ALTERNATIVE TO "M" FOR INITIAL MEC. GROWTH TRHOUGH TANDEM ARRANGEMENT	"M" SELECTED: MEETS ALL INITIAL MEC CRITERIA, HAS GROWTH CAPABILITY AND MEA COMMONALITY	REQUIRE MAJOR MODIFICATIONS FROM MEA-C

*GROWTH CAPABILITY EXISTS IN ALL CONFIGURATIONS. DESIGN IMPLICATIONS STUDIED SPECIFICALLY ONLY IN FOUR CONFIGURATIONS LISTED

Figure 11. Initial MEC Concepts Studied

Figure 12 compares principal features of the spoked disc concept (baseline) with the alternate concept of a standard Spacelab pallet carrying SES and seven MEA facilities mounted on a wine rack type support structure. The SES unit carried on the pallet is similar to the current S/L based SES design. That carried by the spoked disc represents a modified design which is compatible with the available mounting space in the center of the disc.

The spoked disc configuration has the programmatic advantage of providing maximum commonality between MEA-C and MEC in terms of structure and some of the subsystem elements.

The pallet-based configuration benefits from the use of an established primary structure previously integrated with the Shuttle Orbiter on other programs and one that will be in common use by other free-flying Space Platform payloads.

In both configurations the EOS would be attached in tandem to the basic MEC structure.

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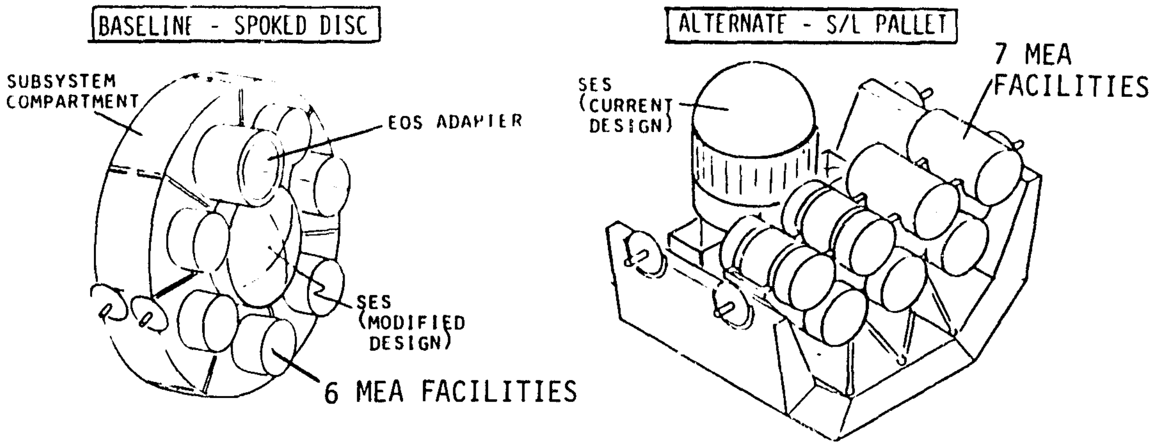

- SPOKED DISC STRUCTURE (ADAPTED FROM MEA-C)
- 6 MEA FACILITIES
- SES (MODIFIED DESIGN) IN CENTER COMPARTMENT
- SUBSYSTEMS IN TRAPEZOIDAL COMPARTMENT ADJACENT TO EOS ADAPTER
- EOS ATTACHED IN TANDEM
- SP BERTHING ADAPTER IN CENTER (FAR SIDE)

- STANDARD S/L PALLET
- 7 MEA FACILITIES ON WINE RACK
- SES (CURRENT DESIGN)
- SUBSYSTEMS PARTLY IN PALLET STRUCTURE PARTLY UNDERNEATH MEA FACILITIES
- BERTHING ADAPTER AT PALLET BOTTOM
- EOS ATTACHABLE IN TANDEM

Figure 12. Initial MEC Configuration Alternatives

Regarding the Advanced-MEA spoked disc design by MSFC, the altneratives of radial and axial payload insertion were considered for MEC. Payload canisters of larger dimensions can be accommodated in the axial attachment mode, if they are allowed to protrude outside one of the bulkheads of the 30 inch thick disc structure. The resulting increment in axial length will not reflect in an increase of Shuttle cargo bay length dependent transportation charges since the EOS berthing adapter, to be attached on the same side, itself protrudes about 25 to 30 inches thus increasing the chargeable length of the vehicle.

Figure 13 shows the MEC and EOS in the alignment used for berthing to the Space Platform aft payload port (+x port). This illustration also shows two other payload ports (+z and -y ports) to which the MEC/EOS might be attached, assuming that four such ports are available on the Space Platform. Six MEA-C type cylindrical payloads of each size are shown protruding from the peripheral compartments of the MEC disc structure, while SES occupies the center compartment. One peripheral compartment, i.e., that located adjacent to the EOS berthing adapter, is used to house the MEC subsystems.

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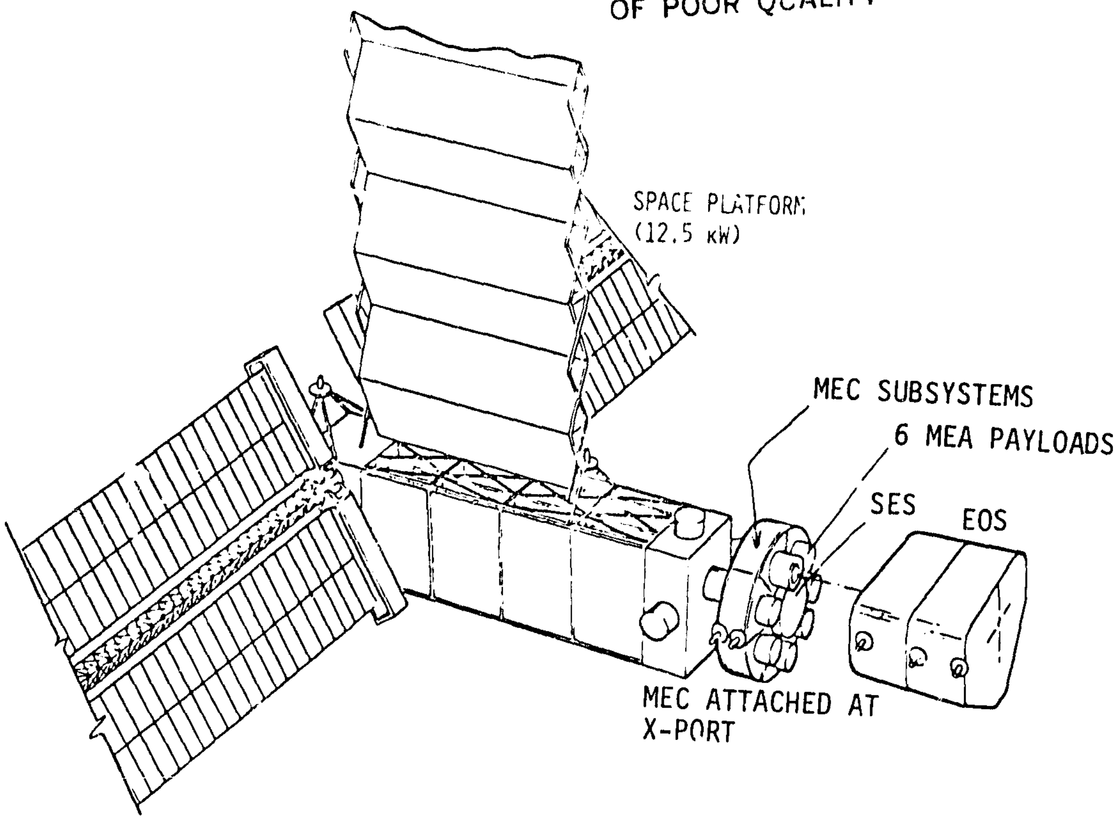

Figure 13. Initial MEC Attached To Space Platform

Figure 14 shows the all-up MEC configuration which uses the initial MEC as a core module with a four-payload growth module attached to the forward bulkhead of the former. As in the initial MEC configuration, EOS is again attached to an off-center berthing adapter placed adjacent to the trapezoidal compartment of the core model that houses the MEC subsystems.

On-orbit serviceability of payloads is a key consideration in the growth from the initial MEC to the all-up MEC design. With orbital stay times of 12 months or more in all-up MEC missions, this means that some payloads that have completed their task can be replaced by others after 6-month intervals, at the time of projected SP revisits by the Shuttle. Smaller, experimental types of payloads carried by the MEC core module are primary candidates for on-orbit servicing or replacement.

A feature keyed to this objective is the provision for moving the EOS assembly out of the way to allow access to core module payloads. The EOS swing-out concept is made feasible by the off-center location of the berthing adapter.

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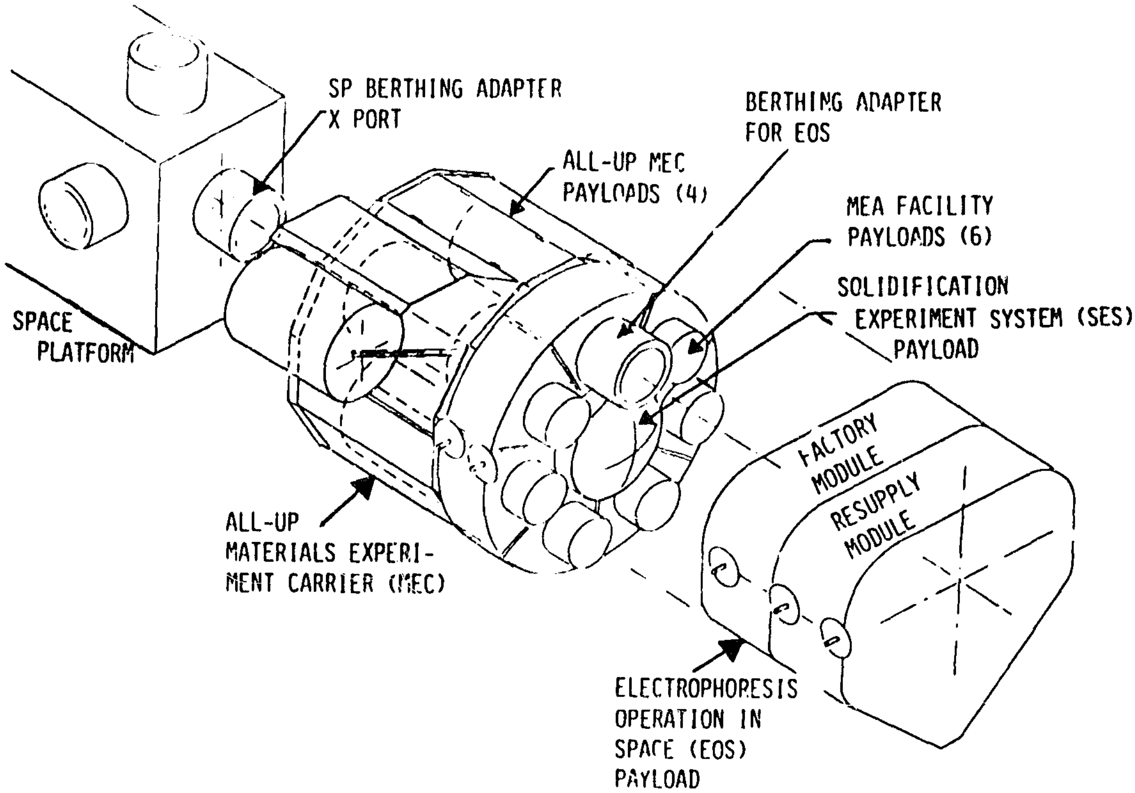

Figure 14. All-Up MEC Configuration With Payloads

In Figure 14 the drum-shaped, twelve-sided growth module of the all-up MEC is shown with one of the four payload compartment doors opened and one payload canister extended on guide rails for servicing or removal. Payload changeout will require handling by the RMS with EVA crew assistance.

Selected MEC Concept Summary

Principal features, dimensions and weight estimates of the selected design concepts for the initial and all-up MEC are summarized in Figure 15. The spread of estimated weights ranges from 8000 to 10,000 lb for the initial MEC and from 14,970 to 26,310 lb for the all-up MEC, including 20% for weight contingencies. The large weight variation in the latter case is due to the 1000 to 3000 lb weight range for each of the four major payload units carried in the growth module, based on results of the payload survey conducted in MEC Study, Part 1. The above weights do not include the 10,000 lb estimated for EOS.

ITEM	INITIAL MEC	ALL-UP MEC
HOST VEHICLE	INITIAL SPACE PLATFORM (12.5 KW)	GROWTH SPACE PLATFORM (25 KW)
CONFIGURATION	MEA SPOKED DISC, MODIFIED 14 FT DIAMETER, 30 IN. NET LENGTH (70 IN. GROSS LENGTH, INCL. ADAPTERS)(1)	INITIAL MEC (CORE MODULE) IN TANDEM WITH GROWTH MODULE (MEC B) 14 FT DIAMETER 130 IN. NET LENGTH (170 IN. GROSS LENGTH, INCL. ADAPTERS) (1)
PAYLOADS	SES, 6 ADVANCED MEA FACILITIES, EOS (ATTACHED IN TANDEM)	SES, 5 TO 6 SMALL PAYLOADS (IN CORE MODULE), 4 LARGE PAYLOADS (GROWTH MODULE), EOS (ATTACHED IN TANDEM)
SUBSYSTEMS	POWER DISTRIBUTION AND CONTROL, THERMAL CONTROL,(2) CDMS, CONTAMINANT CONTROL/RELEASE, STRUCTURE AND MECHANISMS	
EST. WEIGHT (LB)		
STRUCTURE	1330(3)	2850(3)
SUBSYSTEMS	800	960
PAYLOADS(4)	4,480 MIN 6,290 MAX	8,840 MIN 18,300 MAX
CONTINGENCY (20%)	1,390 1,680	2,320 4,200
TOTAL	8000 MIN 10,100 MAX	14,970 MIN 26,310 MAX

(1) ADD 40 IN. FOR SP AND EOS ADAPTERS (DOES NOT INCLUDE 44-IN. EXTENSION ARM)
(2) ALL-UP MEC MAY INCLUDE AUXILIARY RADIATOR
(3) INCL. 160 LB FOR 2 ADAPTERS
(4) NOT INCLUDING 10,000 LB FOR EOS

Figure 15. Selected MEC Concept Summary

Design Implications of MEA-C-to-MEC Evolution

The evolution from MEA-C to the initial MEC and subsequently, to the all-up MEC should be planned with emphasis on system and component commonality where this can be achieved without sacrifice in meeting program objectives and where it results in genuine cost savings.

This consideration translates into a design approach where the all-up MEC definition will have a retroactive impact on design features of the initial MEC. The initial MEC design concept similarly should reflect upon MEA-C and thus influence its design characteristics. Programmatically, this implies interactive system planning with a stress on early MEC system definition, at a time when the MEA-C design concept would not yet be firmly established.

MEC Summary Functional Block Diagram

The block diagram shown in Figure 16 applies both to the initial and all-up MEC design concepts. All interfaces on the Space Platform side (left) are combined in the berthing port. The services provided across the MEC/payload interfaces are shown on the right. In the initial MEC these payloads include SES, six MEA facilities and EOS although not specifically identified in the chart. In the all-up MEC four additional payloads are accommodated. All payload interface connections are similar except for EOS which is attached to an external berthing port.

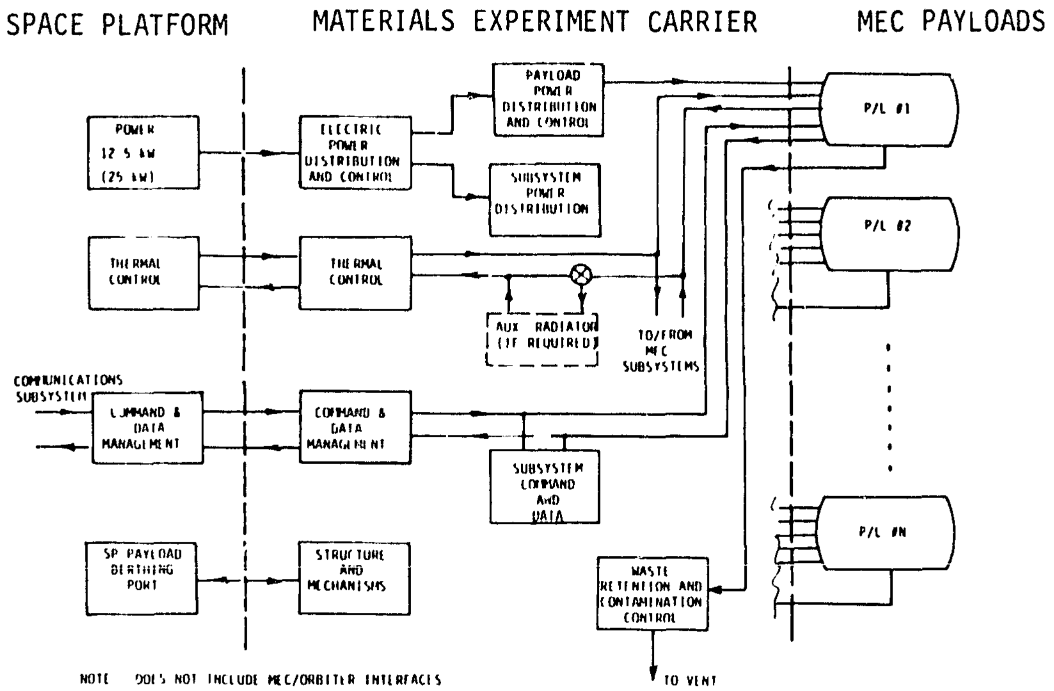

Figure 16. MEC Summary Functional Block Diagram

Interfaces with the Shuttle Orbiter, omitted in this block diagram, will be similar to those with the Space Platform except for involving much lower power supply and thermal control capacities and lower data rate signals to and from the MEC CDMS. Electrical cables and coolant lines will be connected via an Orbiter umbilical. The structural interface between MEC and Orbiter is provided by longeron and keel trunnions on the MEC and by corresponding retention fixtures in the Orbiter bay.

Assessment of Selected MEC Configuration

Figure 17 gives an assessment of the selected initial and all-up MEC design concepts with regard to meeting key functional and operational requirements. Four of these pertain to payload accommodation issues. Three rating levels, 1-satisfactory, 2-good and 3-excellent, are used in this assessment. Most of the MEC design characteristics listed in the table received high ratings. Those with lower ratings are generally of lesser importance. Some require further study, e.g, item 8 which involves constraints on load transfer and worst-case natural bending frequencies for the initial MEC configuration.

CHARACTERISTICS	RATING						REMARKS
	INITIAL MEC			ALL-UP MEC			
	1	2	3	1	2	3	
1. COMMONALITY WITH ADVANCED MEA (MEA-C)			•			•	ADAPTED MEA DESIGN
2. COMPACTNESS			•			•	
3. NUMBER OF PAYLOADS ACCOMMODATED			•			•	UP TO 7 INITIAL MEC UP TO 10 ALL-UP MEC
4. FLEXIBILITY OF PAYLOAD ACCOMMODATION			•			•	
5. P/L SIZE ACCOMMODATED		(1) •				•	(1) LENGTH ≤ 50 IN
6. P/L ACCESS FOR SERVICE/CHANGEOUT							
- ON GROUND			•			•	
- ON ORBITER			•		(2) •		(2) GROWTH MODULE P/L'S INACCESSIBLE IN CARGO BAY
- ON SPACE PLATFORM (SORTIE MODE)	N/A					•	
7. EASE OF GROWTH FROM INITIAL TO ALL-UP MEC			•			•	
8. ORBITER STRUCTURAL INTERFACE	(3) •					•	(3) CONSTRAINTS ON LOAD TRANSFER VIA TRUNNIONS
9. RMS HANDLING ACCESSIBILITY/CONVENIENCE		•			•		GRAPPLE LOCATION
10. COMPATIBILITY WITH SP PLACEMENT CONSTRAINTS	•			•			EXTENSION ARM REQUIRED
11. AUXILIARY RADIATOR PLACEMENT (IF NEEDED)	N/A			(4) •			(4) CONSTRAINED BY EOS

RATING LEVELS 1-SATISFACTORY 2-GOOD 3-EXCELLENT

Figure 17. Assessment of Selected MEC Configuration

5.4 SUBSYSTEMS

The design approach is oriented toward decentralization of support functions. Individual payloads will be designed to provide their own, dedicated power processing, data processing, operational control and sequencing, and other related support. MEC subsystem functions primarily involve control and support of the operation of the MEC system and payloads as a whole. The objective is to permit 1) greater convenience of payload changeout, both on the ground and on orbit, 2) flexibility of payload composition and, 3) autonomy of payload operation. Item 1 implies simplification of the MEC-to-payload interface and standardization of the interface design.

Payload functions and operations with .. MEC are structured in a hierarchy analogous to MEC as a Space Platform (SP) payload. The SP performs executive control over MEC operations but does not get involved in the details of MEC operating procedures, command and data flow, time schedules and processing sequences. Thus, MEC operates largely in an autonomous mode subject to resource monitoring and control by the Space Platform.

Analogously, MEC allocates and distributes resources available from the SP to the various MEC payloads according to a predetermined protocol. It exercises executive control over payload operations but is not involved in, or supports details of payload processing functions and sequences. The payloads thus operate largely in an autonomous mode.

Contingencies anywhere in this hierarchy are first responded to at the local level, to achieve immediate protection and/or correction. A response at the next higher level will be prompted by warning signals and other indications of persistent, uncorrected malfunctions/anomalies at lower level. Automatic system checkout and diagnostic functions are also included as part of MEC centralized control.

The MEC subsystem requirements and implementation summary listed in Figure 18 reflects the decentralized design concept.

5.4.1 MEC Electrical Power Distribution Subsystem (EPDS) Design

The MEC electrical design includes power distribution and control, command and data management and the interfaces between these subsystems and corresponding Space Platform subsystems, on one hand, and MEC payload units, on the other. Functional allocations in the electrical design concept are summarized in Figure 19.

The major EPDS functions are:

1. Interface with SP during free-flying and sortie modes, with Orbiter during ascent and retrieval.
2. Distribute and control main power buses (3 @ 30 VDC, 2 @ 120 VDC) to all payload ports.
3. Provide and control deadfacing switches for all power buses at all payload ports.
4. Support MEC and payload minimum housekeeping loads through non-interrupted priority bus.
5. Provide stay-alive power to MEC subsystems and payloads by a rechargeable battery when no power available from other sources.
6. Provide protection against overloads (payloads, MEC subsystems).

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Subsystem	Requirements	Comments
Structures	• Accommodate payloads, MEC subsystems and payload-required support equipment. Provide ease of access. • Provide adapters for attachment to the Shuttle, Space Platform and RMS.	• Develop on-orbit accessible modular design which provides maximum payload flexibility/interchangeability. • Conform with Shuttle trunnion and keel tiedowns.
Thermal Control	• Interface with (as required) the SP heat rejection system. • Provide temperature control and heat rejection for MEC subsystems, payloads and payload required support equipment.	• Accommodate high and low-temperature payloads and low temperature subsystems and support equipment.
Power Distribution	• Provide interfaces between payloads and SP or Shuttle. • Protect and isolate payloads and SP/Shuttle from each other.	• Receive, condition, distribute, and control power to payloads and MEC subsystems. • Provide EMI and RFI shielding.
Command/Data Management	• Provide interfaces between payloads and SP or Shuttle. • Provide MEC/payload supplemental data storage as required. • Provide command and control of MEC subsystems and payloads in conjunction with SP. • Integration, pre-launch, deployment and on-orbit payload condition checkout.	• Optimize data handling/management between MEC/payload and SP or Shuttle. • Central command and control on MEC, subcommands in payload support module as required. • Provide checkout and diagnostic capabilit·.

Figure 18. MEC Subsystems Summary

GROUND CONTROL (POCC/SPCC)	SPACE PLATFORM	MEC	MEC PAYLOAD
GOALS • Mission planning • Optimum use of MEC, SP and STS • Monitoring/control of flight operations	• Meet user load requirements • Executive control of users • Maintain ground links via TDRSS	• Support P/L load requirements • Maximize productivity of mission • Monitor/control autonomous operations	• Operate cost-effectively and productively • Share resources optimally
POWER DISTRIBUTION & CONTROL • Monitor adherence to resource allocation, mission protocol	• Supply power to users per predetermined allocation • Monitor/control power utilization by P/L's	• Distribute power to MEC payloads per established program • Monitor loads on distribution system • Shed loads if necessary	• Utilize power effectively • Protect against overloads • Provide additional power conditioning
COMMAND/DATA FLOW & MANAGEMENT • Accommodate PI participation in MEC/payload monitoring, control, data analysis • Transmit commands, receive housekeeping & payload data • Exercise MEC control in critical events	• Distribute commands, acquire data from MEC • Executive control of MEC operating modes • Provide data storage for delayed dump	• Control MEC operations • Interface with SP data bus • Distribute incoming commands • Acquire P/L data & transmit to SP for communication to POCC • Executive control of P/L's • Checkout, diagnostic routines	• Control P/L processing sequences • Accept commands • Acquire experiment data, transmit to MEC CDMS • Perform checkout, diagnostic routines
MEC/MEC PAYLOAD INTERFACE CONTROL • Monitor/control interface functions • Accommodate PI participation in MEC/PL interface control • Support critical event control	• Transmit commands to MEC, MEC/PL data to ground in support of MEC/PL remote interface control	• Autonomous P/L operation monitoring & executive control • Transfer commands to P/L, P/L data to SP • P/L time-sharing control	• Autonomous operation under MEC executive control • Protect system against P/L malfunctions, overloads

Figure 19. Electrical System Functional Allocations

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Requirements for initial and all-up MEC differ primarily in power level supplied and number of payloads accommodated.

The EPDS design approach is based on the following:

1. Growth from initial to all-up MEC through increase in power level, and power distribution to added payloads.
2. EPDS functions are essentially similar.
3. Payloads provide own individual power conditioning if SP-provided voltage levels and quality of voltage regulation are insufficient.
4. MEC will provide central power management system to control system health and maximize source power utilization.
5. Payload power interfaces are standardized as much as feasible.
6. Effective CDMS utilization is provided by the power distribution and control design.
7. Use of SP-developed electric power subsystem hardware.

Figure 20 shows a block diagram of the selected SP/MEC/payload power distribution and control concept including MEC/SP and the MEC/payload interfaces.

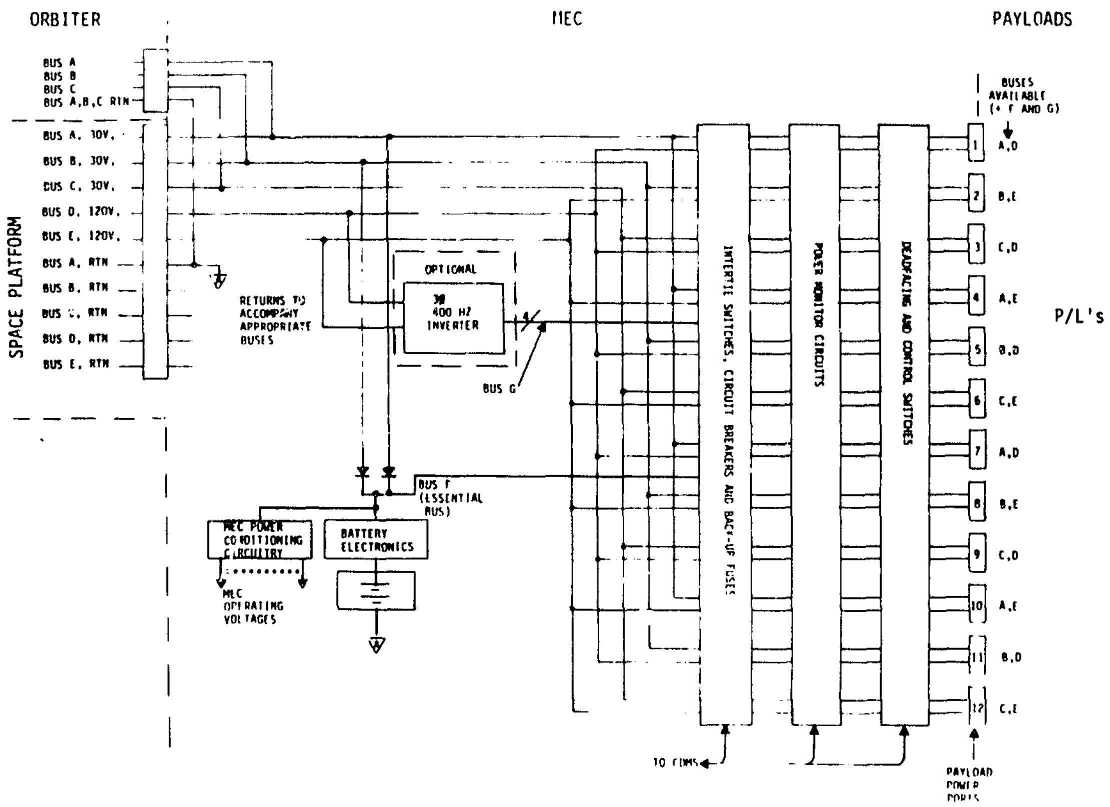

Figure 20. EPDS Functional Block Diagram

In performing the programmed normal operating profile, MEC will monitor all buses to all payloads. If an incorrect power profile use is determined, MEC will command the bus swithces to the respective payload(s) to "off." It htus provides a redundant control function to the payload's internal monitoring/protection system to avert the more serious effect of SP-originated load shedding.

EPDS Transition To All-Up MEC

EPDS growth to all-up MEC capability will primarily require additional cabling, added power control switches and increased auxiliary battery capacity to accommodate the added payload ports. Extra cable length is required to convert the subsystem compartment in the MEC core module to the Space Platform interface adapter via the utility duct in the MEC growth module.

While power distribution cables to each payload port in the core module will be sized for 12.5 kW maximum payload power requirements, those to growth module payload ports will provide up to 25 kW to meet maximum power requirements of unique payloads carried in the all-up MEC.

5.4.2 Command and Data Management Subsystem (CDMS)

The major CDMS functions are:

1. Interface with the SP during free-flying and sortie modes, with the Orbiter during ascent and retrieval.
2. Distribute incoming and stored commands to individual payloads and to MEC engineering subsystems.
3. Acquire and manage all state-of-health, housekeeping and instrumentation data from payloads and MEC subsystem and store as required.
4. Format all data for transmission to the SP CDMS and/or communication subsystem or to the interfacing Orbiter CDMS/telemetry subsystem.
5. Monitor and provide executive control of MEC and MEC payloads.
6. Perform MEC and MEC payload verification and checkout routines on command.
7. Provide flexibility for selecting alternate sequences and reprogramming of CDMS executive software in response to incoming commands.
8. In the all-up MEC, perform fault detection, diagnostics and possibly fault correction functions (thus providing future MEC growth capability).

9. In future MEC operations, provide artificial intelligence required to minimize ground-based, interactive control (e.g., to detect/correct faulty processing products).

The CDMS design approach is based on the following:

1. A CDMS architecture is selected that permits initial MEC simplicity without limiting growth to all-up MEC capability.
2. A central processor (CPU) based I/O scheme controls the command and data flow, electrical power allocation and thermal subsystem.
3. Later addition of computer and mass memory extends MEC versatility and functional autonomy.
4. Use is made of MEA-C existing equipment designs and Space Platform hardware where applicable.
5. Video data handling/processing capability is introduced in the all-up MEC for payloads requiring image data transmission to POCC.

Figure 21 shows the CDMS functional block diagram implementing this design approach.

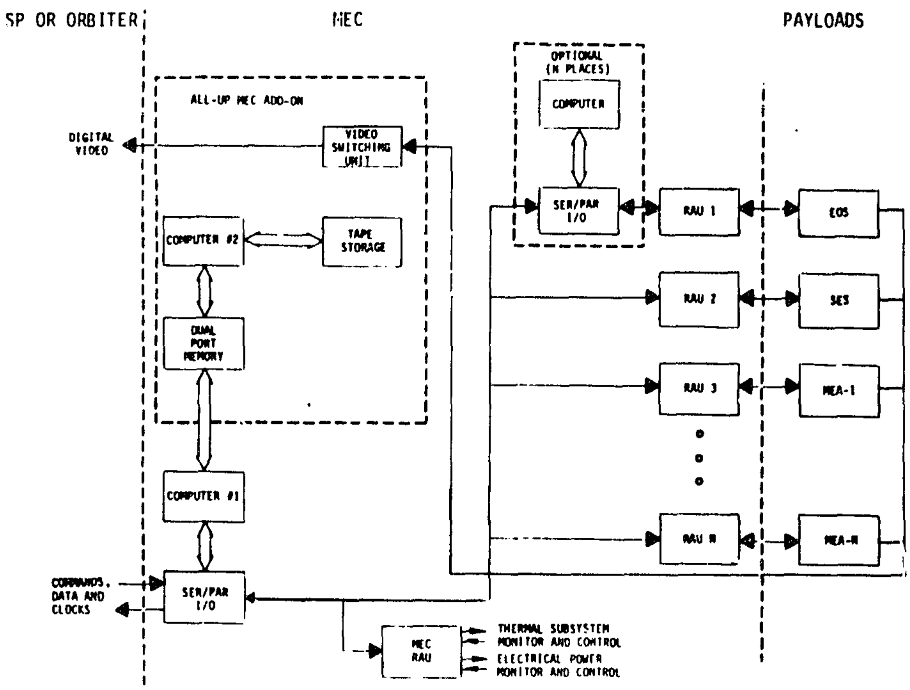

Figure 21. CDMS Functional Block Diagram

MEC Data Rates

Command and telemetry data rates required by MEC and its payloads vary over a wide range with payload composition and operating modes. Estimated maximum command rates for the initial MEC are about 0.5 Kbps. Scientific and housekeeping data rates may range from 12 to 17 Kbps. These requirements are well below the SP/TDRSS forward link (10 Kbps) and return link (46 Kbps) channel capacities in the S-Band multiple access mode.

The low telemetry data rate requirements reflect time-shared payload operations, where only EOS, SES and one or two MEA facilities will be active simultaneously at any time. Elimination of imaging requirements in the initial MEC also is a key factor in holding telemetry bit rates to a low level.

For data rate requirements of the all-up MEC reference is made to results of the payload analysis conducted in MEC Study, Part 1. Maximum command rates were estimated as about 1 Kbps. Telemetry rates, including those for multiple image system outputs, increase to several Mbps, thus requiring using a TDRSS link, K_u-band, single-access channel. Still these requirements are minor compared with projected maximum SP/TDRSS channel capacities.

MEC End-To-End Data Flow

Figure 22 shows the data flow between the MEC and the payload users, e.g., principal investigators, indicating how MEC commands are initiated, verified and intermixed with other SP commands and sent to the SP. The SP then distributes the commands to their proper destination.

In a similar fashion MEC and MEC payload data is packetized and sent to the SP where it is intermixed with other SP data and relayed to earth. The data is then sorted and distributed to the ultimate users.

5.4.3 Thermal Control Subsystem (TCS)

The thermal control subsystem must:

1. Efficiently collect all MEC and MEC payload waste heat and transfer it to the SP for dissipation through the SP radiator. This includes minimizing uncontrolled heat loss to space from payloads or from MEC.
2. Be capable of meeting all payload requirements, including inlet temperatures, flow rates and changes in payload status, active processing and pre- and post-processing.

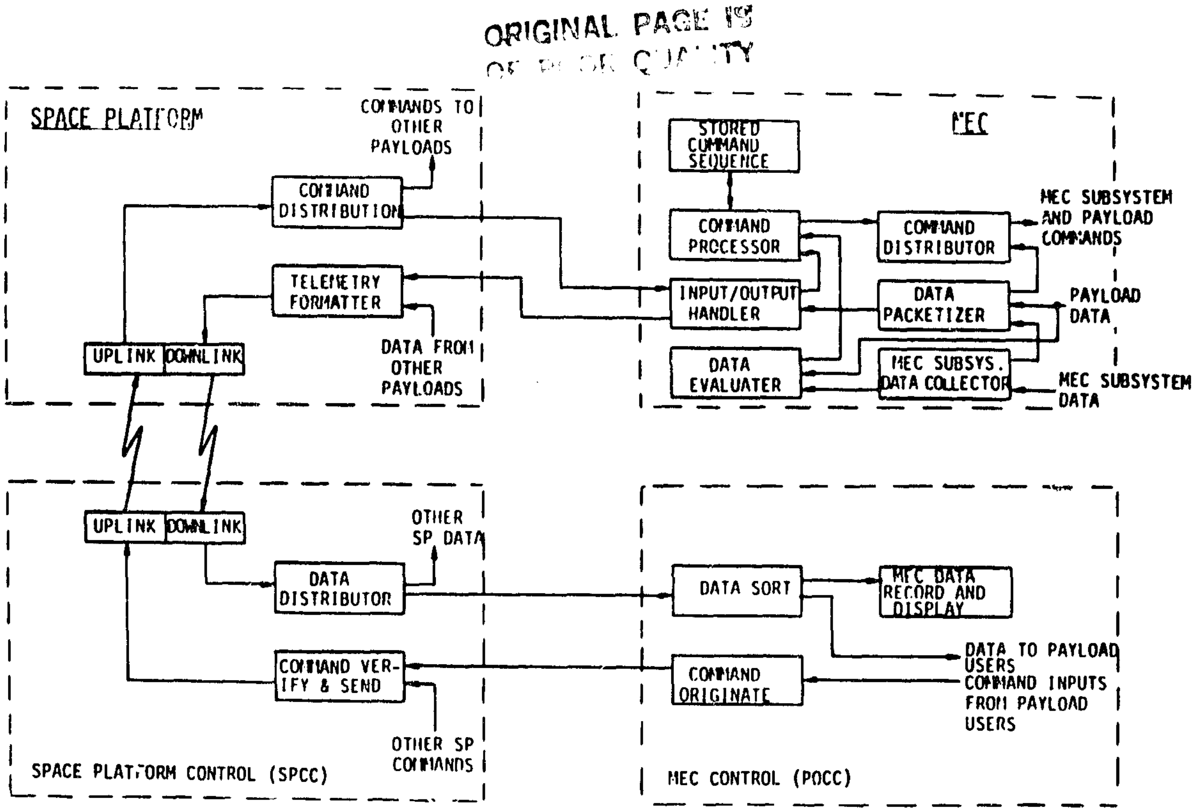

Figure 22. MEC End-To-End Data Flow

Accommodation of EOS as MEC-attached rather than an independent payload, directly attached to SP, is not a firm requirement. However, as discussed earlier, it will be advantageous to provide this capability in order to:

(a) Increase MEC utilization diversity, e.g., as a carrier of commercial-type payloads such as EOS

(b) Make available the extra SP berthing port (which would then not be occupied by the EOS) to other potential SP users

(c) Achieve greater MEC and SP mission flexibility, in general.

The selected approach is based on the following:

1. Both initial and all-up MEC thermal designs accommodate EOS.
2. Safe, reliable, single fluid loop for heat transfer, parallel and redundant pumps for increased reliability.
3. Parallel rather than series coolant flow through all payloads (except EOS) to accommodate diversity and variability of temperature ranges and flow rates.
4. TCS designed for maximum payload requirements during processing operations as well as in pre- and post-processing phases.

5. Adequate insulation between payloads, as required by individual payload characteristics.
6. Heat exchangers and flow control in each coolant loop branch on payload side of the interface, designed to payload-specific requirements.
7. MEC thermal control subsystem design approach uses elements of (1) MEA-C TCS design and (2) Space Platform TCS hardware.
8. The selected TCS design concept for the initial MEC is adaptable to the all-up MEC requirements, thus permitting easy and economical capability growth.

The block diagram (Figure 23) shows the fluid loop configuration and interfaces with the SP and MEC payloads, including EOS, SES and MEA facilities. The SP thermal interface is at the heat exchanger assigned to the berthing port being used by MEC.

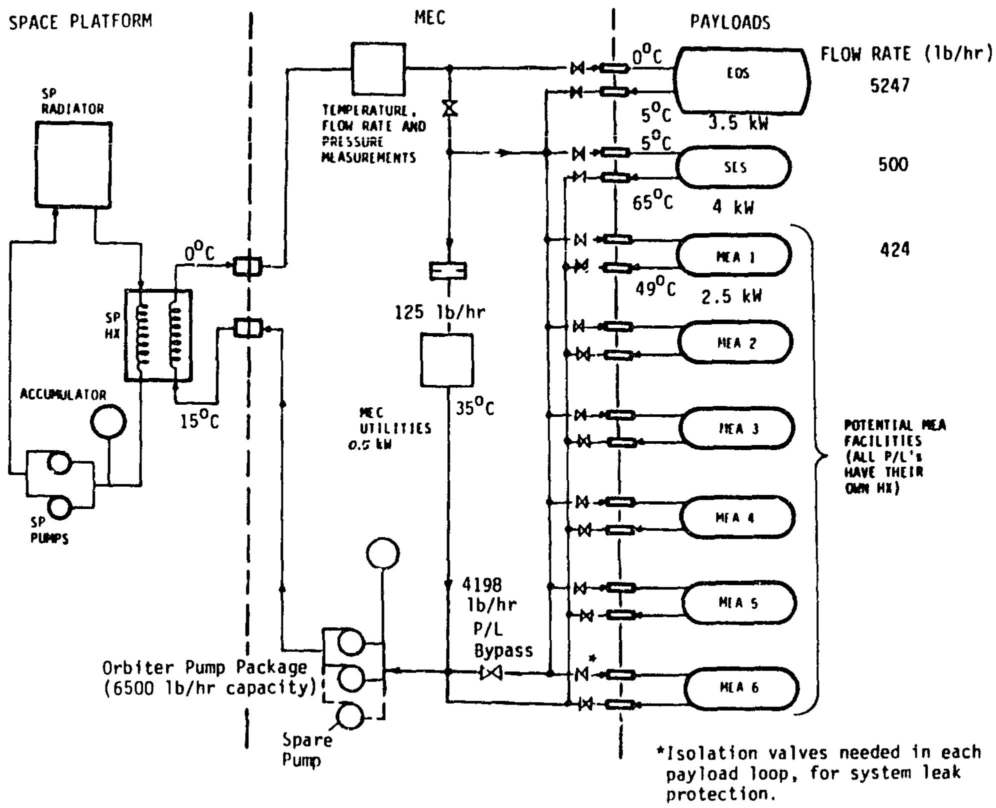

Figure 23. MEC Thermal Control Diagram

Heat transfer from MEC payloads is effected through heat exchangers on the payload side of the interface. Given the diversity and required interchangeability of payloads, the handling of payload-specific heat transfer requirements individually by each payload facilitates interface standardization.

Transition to All-Up MEC

The TCS design requires only minor modifications in the growth from initial to all-up MEC capability. The all-up MEC requires the addition of four paylaod fluid loops and interface equipment. The required pump capacity is dominated by EOS heat rejection requirements (flow rate 5250 lb/hr), both in the initial and all-up MEC. It is apparent that up to 10 all-up MEC payloads with average flow rate requirements of 500 lb/hr each could be readily accommodated by the selected serial/parallel fluid loop design without addition of another pump.

Addition of an Auxiliary Radiator in All-Up MEC

The selected TCS design permits addition of an auxiliary radiator with only minor changes of the basic fluid loop. The radiator fluid lines are connected at one end to the high temperature junction of the parallel payload loops, and at the other end to the pump assembly inlet, bypassing the direct fluid connection between those points. This arrangement permits the radiator to operate at an elevated temperature and, hence, higher heat rejection efficiency than the SP radiator. The objective is to limit the auxiliary radiator to a size that would permit wrap-around stowage against the MEC body.

Figure 24 shows a deployable auxiliary MEC radiator sized for wrap-around stowage on one side of the MEC hull. In the deployed position it is parallel to the SP radiator. The radiator has five hinged active panels with a total area of about 120 ft^2. Deployment is by spring action controlled by two actuator-released restraint cables. These cables also serve to retract the radiator for re-stowage. Deployment and retraction is performed by remote control, but can be assisted by crew EVA if necessary. When deployed it does not restrict MEC payload access for servicing.

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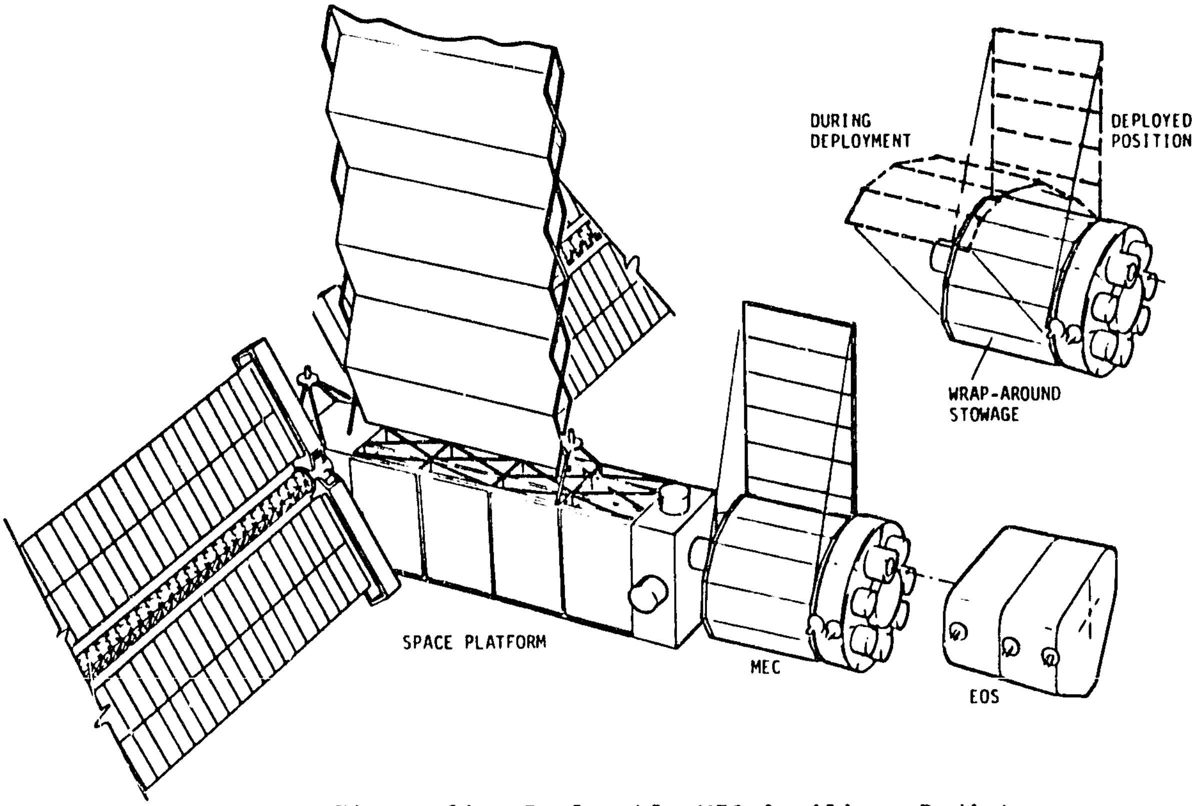

Figure 24. Deployable MEC Auxiliary Radiator

As an alternative the use of body-mounted radiator panels attached to the payload compartment doors on both sides of the hull also was considered (Figure 25). The effective radiator area would be about the same as in the deployed case, but some of the panels would be periodically exposed to sun illumination with some loss in overall heat rejection efficiency. This concept is simpler and avoids the problem of potential interference with adjacent SP payload clearance volumes.

5.4.4 Structure and Mechanisms Subsystems

This subsystem will be designed to:

1. Carry diversified payload complements including SES and MEA facilities (initial MEC configuration).
2. Carry additional larger payloads projected for all-up MEC missions.
3. Accommodate EOS as an added external payload (both in initial and all-up MEC missions).
4. Be compatible with Orbiter load environment, including maximum static, dynamic and acoustic loads.
5. Provide load transfer via sill and keel support trunnions within MEC safe structural design limits and Orbiter interface constraints consistent with worst-case launch and landing loads.

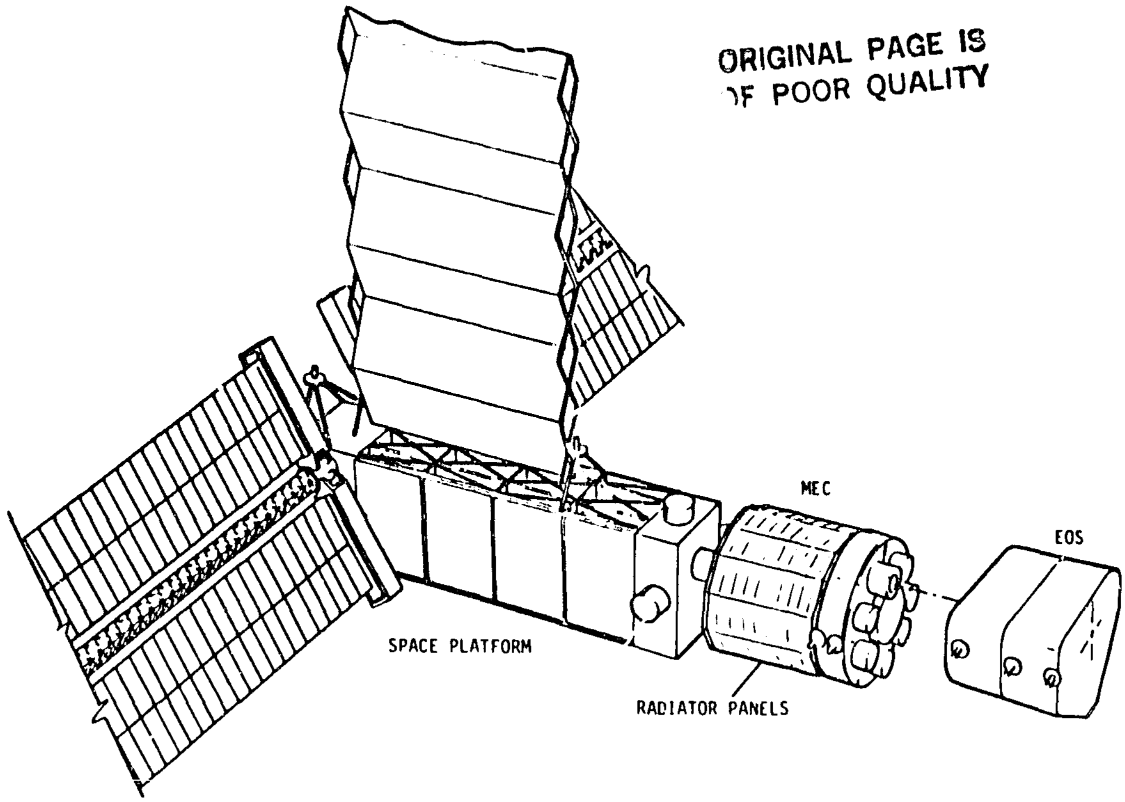

Figure 25. Hull-Mounted Auxiliary Radiator Concept

6. Avoid natural frequencies that would be coincident with Orbiter frequencies to minimize dynamic interaction problems.
7. Keep MEC internal stresses limited to acceptable levels.
8. Be compatible with RMS handling when being moved from/to Orbiter bay and to/from Space Platform.
9. In all-up MEC, permit RMS and/or crew access to attached MPS payloads for servicing or replacement.
10. Provide berthing adapters for SP and EOS attachment, consistent with SP and SP companion payload clearance restrictions. The adapters will be standard hardware items to be defined in SP design.
11. Provide one (or more) RMS end effector grapple fixtures.
12. Provide crew access supports such as handrails and foot rest attach points.

With the Advanced MEA spoked disc design (appropriately modified) adopted as the preferred initial MEC support structure, some of the results obtained in the NASA/MSFC Advanced MEA Design Study were directly applicable and provided a basis for determination of MEC structural load and frequency characteristics.

Design Concept

The modified MEA spoked disc structure of 170-inch outer diameter and 30-inch width includes a seven-sided central compartment, sized to accommodate the 60-inch diamter SES payload, and seven truncated, pie-shaped peripheral compartments that accommodate six MEA facilities and the MEC support subsystems.

The bulkhead covering the disc on one side is designed to carry the end-mounted MEA canisters as cantilevered loads. Subsystem equipment is mounted to the bulkhead or the compartment walls. The bulkhead also support most of the MEC electrical cabling and coolant ducts. The SP berthing adapter is attached to the center of this bulkhead with direct load transfer to the hub structure.

The bulkhead on the opposite (aft facing) side has openings that permit axially mounted payloads to protrude, if necessary. These openings provide access for payload ground installation or servicing. They also make payloads accessible in all-up MEC missions for on-orbit servicing or replacement.

The hull, ribs, hub and bulkheads are of aluminum construction, with stiffeners mounted inside along all edges. Access door covers are designed to be firmly bolted down before launch, to restore some of the stiffness lost due to the aft bulkhead openings. Additional stiffening may be necessary to increase MEC natural frequency.

In an effort to raise the MEC natural frequency to the desired range above 16 Hz several approaches were investigated:

a) Closely-spaced bolt patterns for payload access doors.
b) Additional cross-bracing.
c) Additional door bracing to minimize the effects of access doors.
d) Increase of disc width for greater stiffness.

Item d) promises to produce the desired frequency increase without major design complication, albeit at the cost of a significant weight increase. The recommended approach (e.g., if an existing MEA structure were to be modified for MEC use) is to add an extension disc of 20-inch thickness raising the frequency from 12 to about 20 Hz, (see Figure 26).

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This would not mean additional chargeable MEC cargo bay length, since only the space otherwise allocated to the EOS adapter is taken up by the add-on MEC.

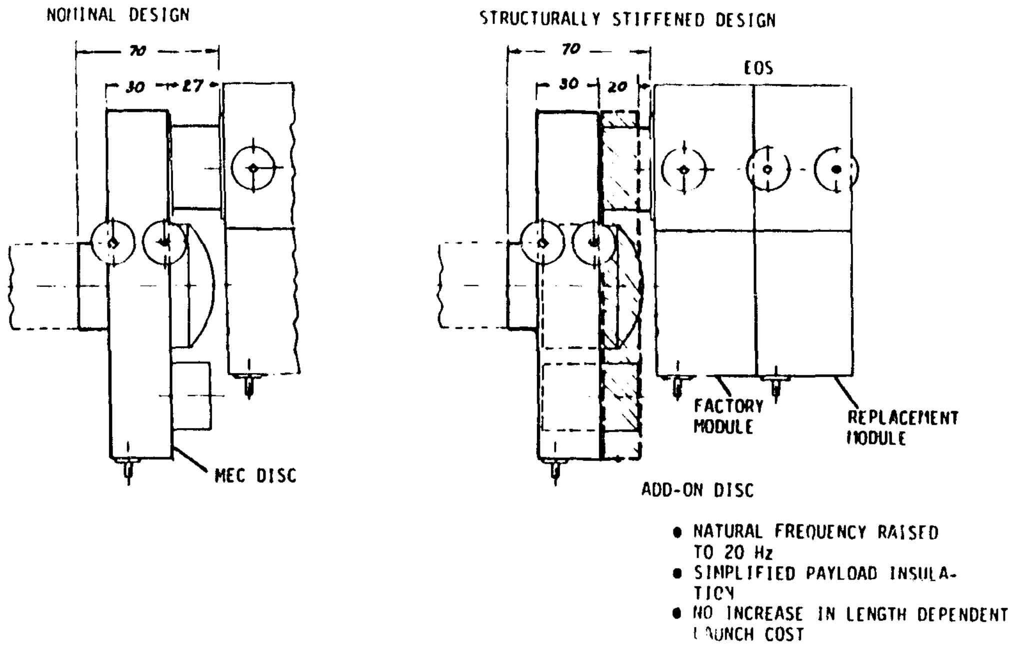

Figure 26. MEC Structural Stiffening by Add-On Disc

Subsystem Relationship of Initial MEC to Advanced MEA

Figure 27 indicates the areas of the initial MEC subsystem design that have commonality with advanced MEA subsystems. It is apparent that, except for the nearly identical support structure, there are only few MEA subsystem components directly applicable to MEC. However, the subsystem design concepts show simularities except for sizing and a degree of flexibility reflecting the differences in mission profiles, operating modes, payload complexity and diversity.

With the MEA design not as yet firmly established at this time, an effort to develop subsystems with an architecture and characteristics compatible with subsequent evolution to MEC requirements is appropriate.

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STRUCTURE:	• MEA spoked disc adapted to initial MEC with minor modifications. Axial payload access. • Center compartment enlarged to accommodate 60 in. diam. SES • SP and EOS berthing adapters added to disc structure.
ELECTRIC POWER:	• Differences in power level and voltage levels (3 to 4 kW, 30 VDC for MEA; 12.5 kW, 30 V and 120 VDC for MEC) require redesign of EPDS, with little or no commonality.
THERMAL CONTROL:	• Both MEA and MEC use pumped coolant loops with parallel rather than serial flow through payloads. • MEC requires larger heat transfer capacity, larger flow rates (EOS accommodation), hence redesigned fluid loop • Selection of Freon 21 as coolant permits commonality of some components
COMMAND AND DATA MANAGEMENT:	• Some subsystem architecture commonality between advanced MEA and MEC (serial data bus approach). • Adaptation to MEC of DACS, used on MEA, or some of its components. • Major operating idfferences (MEA stores all data, MEC periodically stores and dumps data via SP downlink, requires full autonomy, longer mission duration) preclude design commonality.

Figure 27. Subsystem Relationship of Initial MEC To Advanced MEA

5.4.5 Breadboard/Brassboard Planning

Breadboard and brassboard design and planning for the initial MEC should consider the MEC subsystems of: structure/mechanisms, power distribution, thermal control, command/data management, and the candidate MEC/MPS payloads. The payloads considered should scope the range of potential MPS discipline applications including Isothermal, Gradient Freeze, Directional Solidification, Containerless Processing (acoustic, electromagnetic, electrostatic), Bioseparation and Solution/Vapor Crystal Growth. In the setting up of a first step MEC breadboard plan for future implementation, critical elements of at least three of the above payload disciplines, in addition to the critical MEC subsystems elements, should be considered in the make-up of an integrated breadboard. Decision as to the extent of MEC subsystems functions and the specific payloads to be pursued in breadboard/brassboard planning should be made in time to incorporate the plan into downstream, Phase B, MEC design activity.

The MEC breadboard/brassboard concepts should be established per the following groundrules:

1) Low cost initial utilization
2) Conservative growth of total simulation capability.
3) Flexible adaptation to a variety of MEC subsystems and MEC payload sizes, groupings, and system performance levels.

4) Maximum hardware integration simplicity

5) Optimum diversion between MEC subsystems development, MEC payload development, and MEC interface definition.

Key objectives of breadboarding electronic circuits and systems include the following:

1) To verify the ability of circuits, as designed to perform their desired tasks.

2) To experimentally characterize component parameters that are still unspecified,

3) To validate a design experimentally when analytical validation is impractical or impossible.

4) To facilitate comparison of competitive approaches for the purpose of selecting an optimum approach.

5) To evaluate a portion of an existing piece of equipment for a new application.

6) To provide test circuits, in lieu of final hardware, to allow test of partial or complete systems and to study the integration of various portions of systems.

7) To provide a functioning system which will allow one phase of a program to proceed independent of the final hardware and other phases of the program.

Critical MEC design elements such as the following are recommended for breadboarding:

- Adaptive intelligence part of the CDMS operation in concert with simulated MEC payloads.
- Networking of electrical power distribution/control
- Real-time payload control using a remote operator to simulate a MEC flight-ground based operator situation
- Payload sample insertion/retrieval
- MEC-to-MPS payloads thermal interfaces

5.5 SYSTEM AND MISSION OPERATIONS

Principal MEC mission phases include:

- Launch by the Shuttle Orbiter
- Rendezvous with the Space Platform
- MEC attachment to the Space Platform
- Orbital deployment of SP/MEC as free-flyer
- Materials processing operations on orbit
- Retrieval by the Orbiter and return to ground

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The sequence of on-orbit operations required to deploy the MEC during a Shuttle/Space Platform rendezvous mission is illustrated in Figure 28. After rendezvous, retrieval and berthing of the Space Platform on a berthing port provided for this purpose in the Orbiter cargo bay, the MEC will be removed from its stowed position and attached to one of the SP payload ports. When attached, the SP/MEC will be checked out as a functioning system before release by the Orbiter to start free-flying operations. Similar sequences will be employed in MEC retrieval from orbit and on-orbit servicing activities.

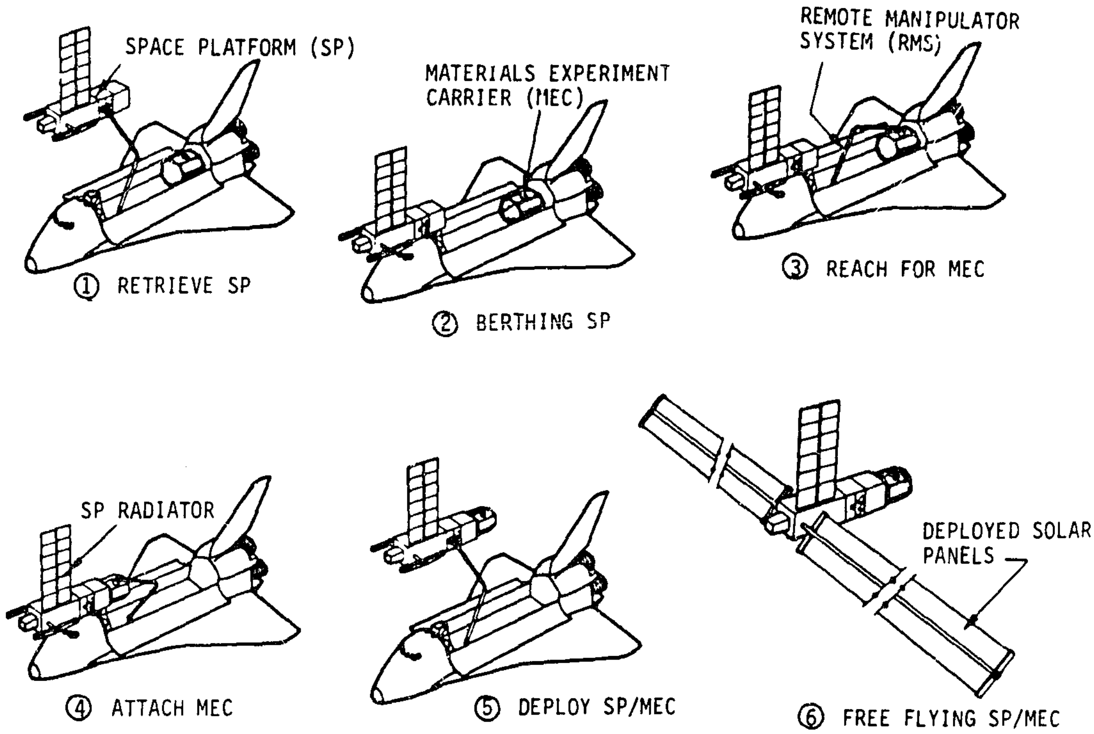

Figure 28. MEC Deployment Sequence

5.5.1 <u>On-Orbit Servicing</u>

On-orbit servicing will increase all-up MEC mission cost effectiveness, by

- Extending mission duration and thus increasing mission output, i.e., the number of samples processed per mission,
- Reducing the number of MEC launches and retrievals required per year, thereby greatly reducing transportation costs,
- Achieving improved payload/mission matching, and more effective Space Platform utilization by MEC, e.g., through replacement of payload units that complete their mission objectives ahead of others
- Timely return to earth of processed material (commercial impact)

MEC payloads will have design interface characteristics that are consistent with, and facilitate on-orbit servicing. Servicing operations will include either exchange of entire payload units or replacement of sample magazines within payloads. Possibly, maintenance, repair or replacement of subsystem elements also will be carried out, if required. Figure 29 compares objectives and design implications of payload changeout vs. sample changeout.

OBJECTIVES

Payload Changeout

- Matching of payload productivities
- Orbital accommodation of new or additional payloads at favorable times

Sample Changeout

- Early sample return for analysis on ground
- Limited sample shelf-life in orbit: biologicals

MEC/PAYLOAD DESIGN IMPACT

Payload Changeout

- Autonomy of payloads
- Simple payload attachment, interfaces
- Ease of on-orbit access and handling
- Interchangeability
- Ruggedness to withstand handling

Sample Changeout

- Accessible/removable storage magazines
- Unobstructed access into enclosures
- Protective sample enclosure required
- Crew hazard avoidance in access, handling

Figure 29. Objectives and Design Implications of Payload and Sample Changeout On Orbit

Principal factors favoring on-orbit servicing are the need for fewer launches of the large all-up MEC vehicle, save transportation and ground refurbishment costs, and greater mission flexibility. However, several other factors tend to limit the potential cost savings: the extra cost of providing MEC with serviceability features; more complex operations during SP/MEC revisits; and the procurement and repeated launch of a separate payload carrier (Service Support Assembly).

Preliminary assessment has shown that the advantages of the on-orbit servicing option outweigh its disadvantages and support the decision to provide MEC with the design features required for serviceability.

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5.5.2 Resource Utilization

Limitations of available resources, particularly on the initial 12.5 kW version of SP, demand that all users perform their missions as economically as possible. Ideally, any significant extra amount of power, temporarily unused by one SP payload, should be channeled to other payloads that can effectively utilize it. With MEC generally being the user that consumes the largest share of available SP power, its mission profile and operating sequence must be carefully planned to satisfy MEC power requirements while still allowing adequate power allocation to other users.

Typical MEC missions will carry a mixed payload with short, medium and long processing time requirements which may be accommodated in a staggered operation. This avoids drawing more power at any time than can be allocated by the Space Platform.

By current estimates, only 7 to 9 kW of average power might be allocated to MEC on typical mission profiles of the initial 12.5 kW Space Platform. The initial MEC payload complement has a projected average power requirement of about 10 kW, even with MEA payloads operating in a fully time shared mode, see Figure 30. The maximum power required for the combined EOS, SES and MEA payload operation would exceed the available power supplied by the SP by more than 1 kW even if MEC were the only user. Specific MEC power utilization profiles must be established as part of MEC mission planning.

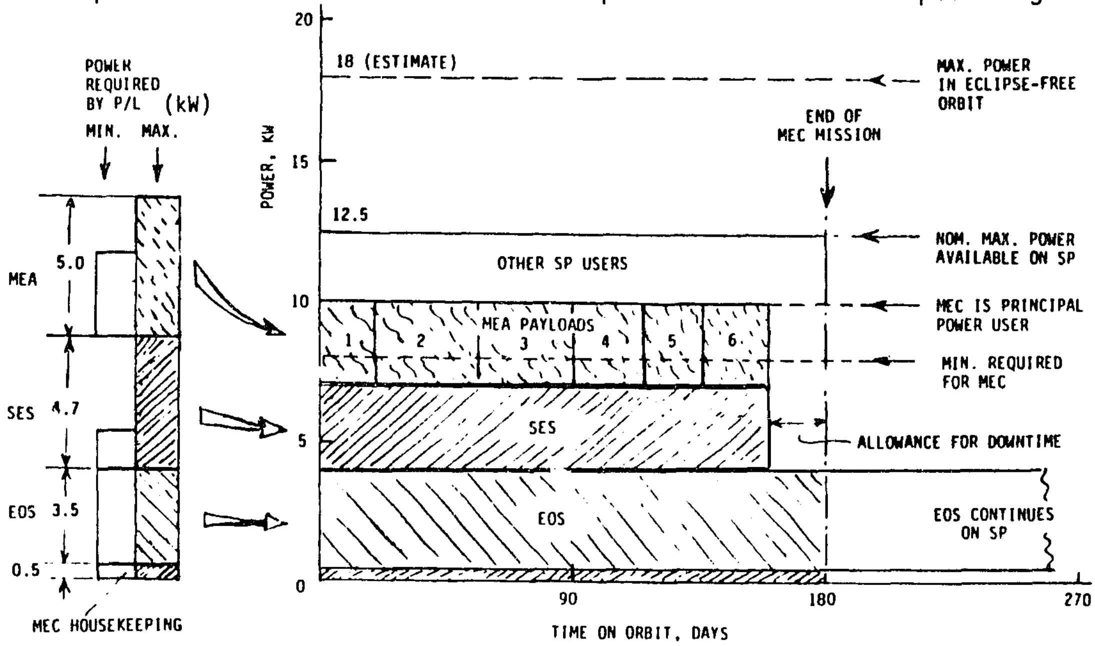

Figure 30. Power Sharing by Initial MEC Payloads

5.5.3 Ground-Based Control

The MEC system and its payloads are designed to operate primarily by programmed automatic sequences supplemented by monitoring, command and reprogramming instructions from the ground if necessary. A maximum degree of autonomous operation is desirable, and reliance on ground-based modes minimized. Replacement of human operator monitoring and remote control functions by fully automated control will depend on the degree to which the system will incorporate machine intelligence and fault-tolerant design techniques.

Even with the anticipated increase in automated operations, however, interactive ground-based control modes of critical MEC processes must still be provided, including telemetry of image data (in all-up MEC) to ground control personnel at the MEC Payload Operations Control Center (POCC).

Autonomous fault correction will have to be developed as a part of MEC technology evolution. This evolution should ultimately lead to the capability of automatically detecting and correcting not only equipment failures, but also processing faults or degradation. Initially this will require remote monitoring by ground control.

5.5.4 Safety

The MEC Mission in all of its phases inherently presents hazards which may cause damage or injury to equipment and personnel including:

- Ground facilities and/or crew
- Shuttle Orbiter and/or crew
- Shuttle payloads other than MEC
- Space Platform
- Space Platform payloads other than MEC

Such hazards must be reduced to a minimum/acceptable level by strict adherence to safety policies and guidelines in equipment design and handling procedures, by eliminating hazardous operating conditions, and by careful attention to environmental hazards the system may be exposed to. This was emphasized, even in the earliest concept definition phase of the study.

NASA safety requirements and guidelines were reviewed during this study and all efforts made to make MEC design and mission concepts compatible with these requirements.

Examples of potential hazard sources and hazardous operations in the MEC mission include the following:

1. Ground handling during MEC integration and checkout, Shuttle installation, post-flight removal, transportation and refurbishment.
2. Shuttle transportation to and from orbit.
3. Shuttle on orbit operations involving MEC handling during deployment, servicing and retrieval phases.
4. Handling by the TMS.
5. MEC operations as SP payload, in the free-flying mission phase, during departure from, and rendezvous/docking with the Orbiter.

5.5.5 End-To-End Mission Assessment

Figure 31 gives an overview of relevant factors in end-to-end assessment of MEC mission characteristics. The emphasis is on interrelations of MEC with other participating elements involved in and/or supporting the mission. These factors are listed next to each participating mission element that interfaces, directly or indirectly, with MEC operations. Entries with solid bullets are those characteristics that rate high marks in the mission effectiveness assessment. Open bullets indicate areas of some concern in terms of special support requirements, constraints, or conflicting requirements between MEC and other users. However, all of these are of a kind that can be resolved by appropriate mission planning or increased resource allocation.

Figure 32 gives an overall mission assessment for the initial and all-up MEC concepts. This chart shows that initial MEC missions, despite their limited performance range, still rate high in cost effectiveness and resource utilization of the early 12.5 kW Space Platform. All-up MEC missions provide the expected performance improvement on most counts, especially in terms of mission flexibility, through servicing and overall payload accommodation, owing to longer mission durations and greater SP power level.

5.6 PROGRAMMATICS

The major output of the programmatics effort was the generation of an implementation plan for the development and operation of the initial MEC and the estimation of costs to accomplish the work of the implementation plan.

Figure 33 is a summary schedule showing the initial MEC design, manufacture and testing, integration and testing of MEC and its subsystems, MPS payload integration, and ground/flight operations. The schedule,

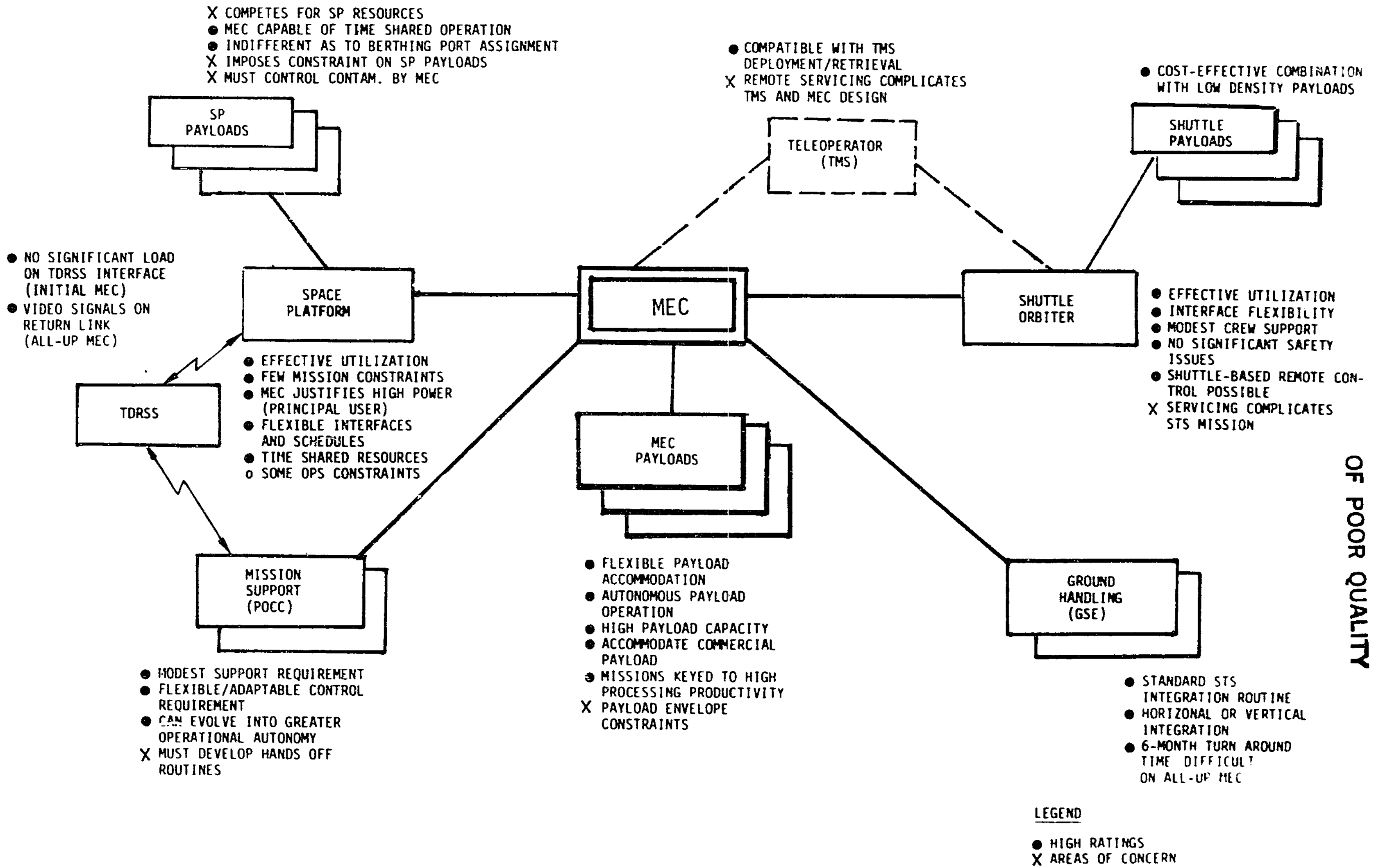

Figure 31. Key Factors in MEC Mission End-to-End Assessment (Interactions)

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CHARACTERISTICS/CRITERIA	RATING: INITIAL MEC 1	INITIAL MEC 2	INITIAL MEC 3	ALL-UP MEC 1	ALL-UP MEC 2	ALL-UP MEC 3	COMMENTS
1. Payload Accommodation							
- Resource Capacity		●				●	
- Flexibility/Versatility		●				●	
- Growth Capability			●			●	
- Autonomy			●			●	
- Payload Mix (long/short missions)		●(1)				●	(1) Fixed 6-month missions
- Commercial Payloads and Quick Look, Unconventional Payloads	●(2)					●	(2) Size and accommodation constraints inherent in concept
2. Shuttle Utilization							
- Length/Weight Economy			●		●		
- Compatibility With Launch Schedule			●		●(3)		(3) 6-month turn-around is tight
- Ease of Accommodation (other P/L's)			●		●(4)		(4) All-up MEC rides in mid/aft bay
- Crew Capability Utilization		●(5)				●	(5) No servicing on orbit
- Safety			●			●	
3. Space Platform Utilization							
- Resources Exploited			●			●	
- Flexibility of Requirements		●(6)				●	(6) Uses 80% of available power
- Ease of Accommodation (other users)		●				●	
4. Other							
- Ease of Servicing On-Orbit	—	N/A	—		●(7)		(7) Configuration-constrained
- Ease of GSE Support			●		●(8)		(8) Tight turn-around schedule
- Ease of POCC Support			●			●	
- Ease of TDRSS Support via SP			●		●(9)		(9) Imaging data exceed SMA channel capacity
- Evolution Potential			●			●	

RATINGS 1-Satisfactory 2- Good 3-Excellent

Figure 32. End-To-End Assessment of MEC Mission

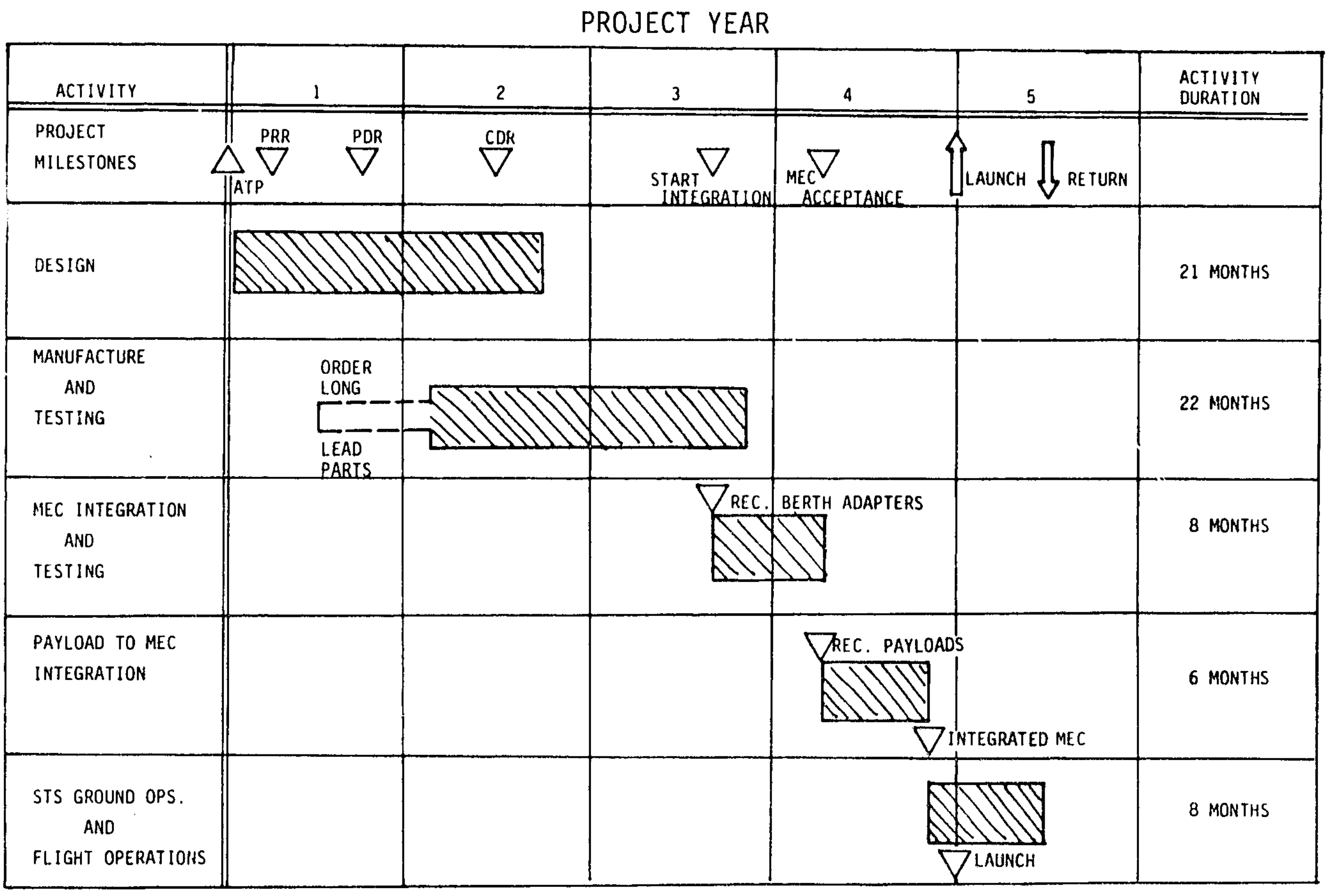

Figure 33. MEC Project Schedule

considered conservative, shows 48 months from start of hardware start to first flight. Key project milestones are:

- Preliminary Requirements Review at 3 months
- Preliminary Design Review at 10 months
- Critical Design Review at 18 months; resolve all TBD's before CDR
- MEC acceptance by NASA at 40 months
- Launch at 48 months
- Return to earth

The assumed date for the MEC hardware authority-to-proceed (ATP) is January 1984.

For costing purposes, a project work breakdown structure (WBS) was developed that reflects the: 1) major elements for the initial MEC concept and 2) costing guidelines established at the outset of the cost estimating work.

The guidelines are summarized as follows:

- Design and build one initial MEC, integrate with the three baseline MPS payloads (EOS, SES and MEA), and provide support for one flight
- Budgetary price estimate for each cost cell on the MEC Project WBS
- Price to be in 1982 dollars
- Spread price for real-year dollars or project from ATP Phase C/D through first flight. Consider the project ATP to be January 1984. Use 9% inflation factor for real-year price spread.

The price for the initial MEC was estimated to be $57 million, 1982 dollars. Figure 34 indicates a breakdown of this price by project element.

The $57 million is summarized as follows:

Design and Development	$31 M
Unit Price (Recurring)	$20 M
Operations (Recurring)	$ 6 M
TOTAL	$57 M (1982 dollars)

Figure 35 depicts the initial MEC project price spread in real year dollars. On this figure, project year 1 is 1984. Integration of real year price values over the 4½ years of the project, with the 9% inflator factor incorporated, results in a budgetary estimate of $70 million.

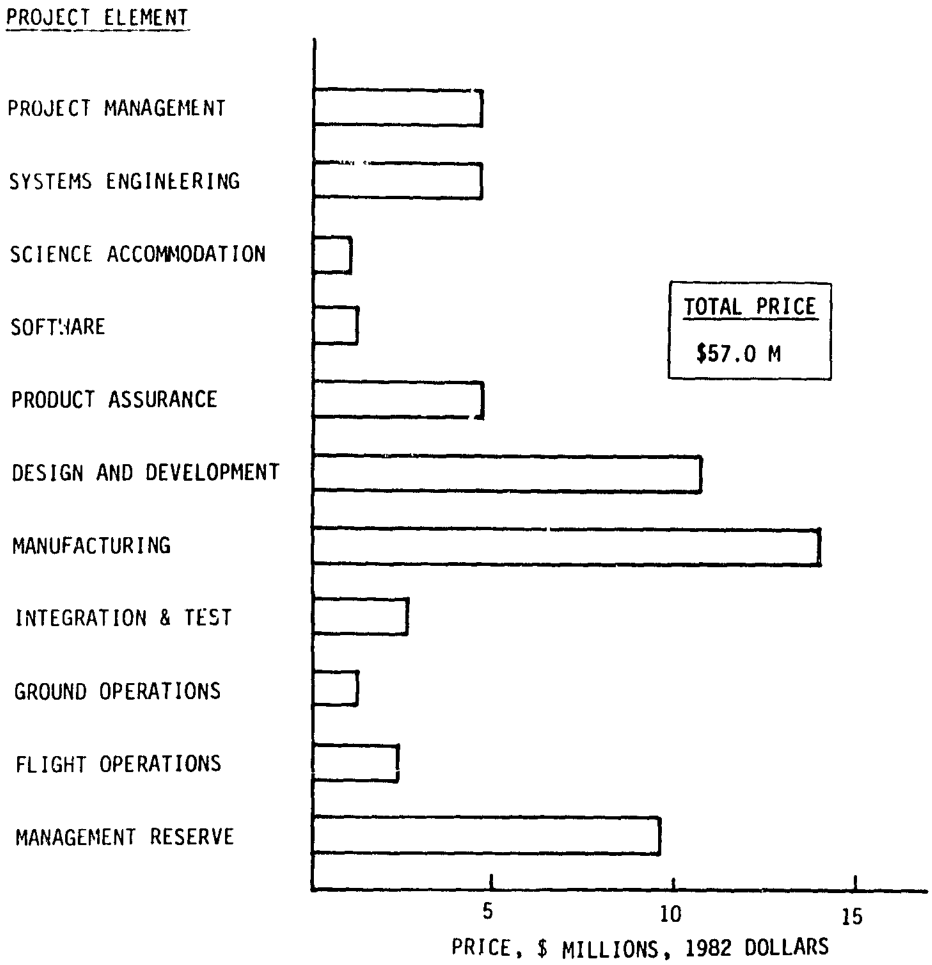

Figure 34. Initial MEC Project Estimated Price

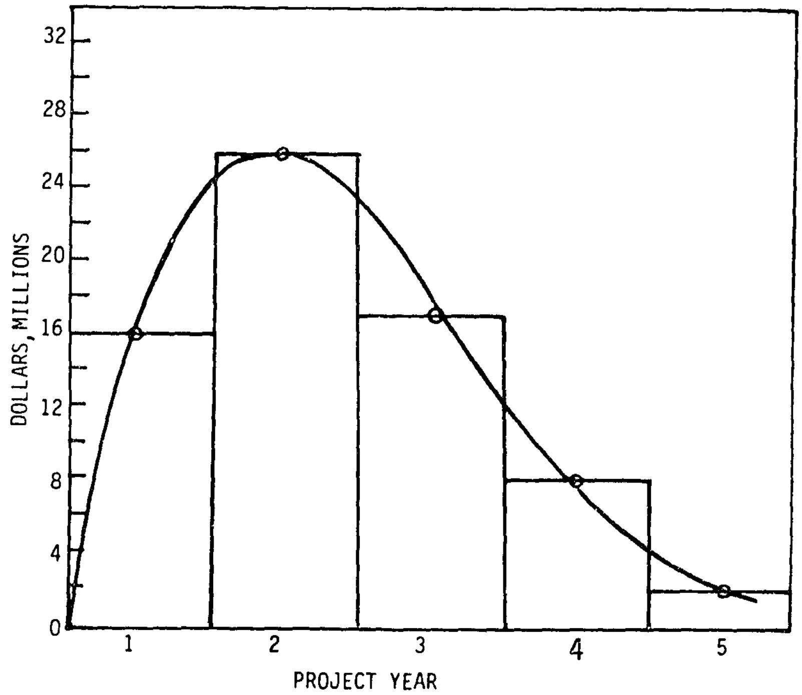

Figure 35. MEC Project Price Spread (Real Year Dollars)

6.0 TECHNOLOGY REQUIREMENTS

The selected MEC concept, including both the initial and the all-up MEC systems, can be developed, built, and operated through use of established space technology. No major advances in spacecraft and subsystems hardware are required to accomplish early MEC missions.

6.1 TECHNOLOGY GROWTH

Inheritance of flight proven technology based on Shuttle and Spacelab MPS hardware, software and operational procedures, will aid in the evolution of the MEC program. Even in early Shuttle-pallet MPS missions some payloads (Solidification Experiment System maybe an example), will function largely as automated units with little or no human operator control intervention. Future automated MPS experiments also are expected to be developed via initial Shuttle/Spacelab mission exposure before they will be converted to free-flying operations for extended durations. New departures in most of the technical disciplines of power control, thermal control, data management, instrumentation and mechanism design that are peculiar to materials processing will thus be avoided.

The evolving MEC program has several intriguing areas that will profit through development of advanced systems and/or components from related projects that parallel MEC. The entire NASA low earth orbit platform program includes the Space Platform, Science and Applications Space Platform, Teleoperator Maneuvering System, and MEC. Concurrent development of these platforms should allow for advanced technology and hardware development to flow to each. Examples are:

1) Rotating mechanical joints that allow leak free fluid flow across the interface. Also thermal control pumps, valves, heat exchangers, and radiators.
2) Quick disconnect hardware that allow ease of access to replaceable/serviceable equipment.
3) Standard docking/berthing adapter devices.
4) Lighweight electrical power system combined with the requirements for autonomous operations, high voltage, high power, survivability/environmental effects for long life missions.

Like the MEC project itself, the associated technology needs will expand as the project evolves from initial to all-up versions. The initial MEC 1987 or 1988 flight will require no new technology based on the assumptions that it will accommodate three highly autonomous payloads on missions with a preprogrammed protocol of payload operations and no on-orbit servicing. In the long term, an all-up MEC system is envisioned that contains sophisticated automation/intelligence functions built into the command/data management subsystem (CDMS), as an evolutionary growth to match the evolutionary progress of the MEC vehicle and its advanced payloads. The advanced CDMS will be capable of optimizing the mission product despite payload operational sequence changes, MEC mission contingencies, and anomalous events.

6.2 SPECIAL PROJECTS

While no new technological development needs have been identified to implement the MEC project with an initial capability for 1987 flight, the following three areas are recommended for technology study to aid in the successful evolutionary growth from the initial to the all-up MEC configuration.

6.2.1 Narrowband TV or Imaging Systems for Ground Based Experiment/Payload Control

This requirement originates with certain crystal growing processes that, in the laboratory, require manual control by a skilled technician during critical phases. In this same discipline, certain anomalies in the crystal growth can be detected visually and the process corrected or terminated if necessary. Although full commercial TV discrimination range and time response would be desirable for performing these tasks remotely, the difficulty and cost of providing such a system, on demand, in real-time, makes it necessary to re-evaluate the imaging requirements.

The minimum mandatory information content of the image should be established for each process and process phase that must have remote manual assistance. It is expected that, in most cases, adequate information can be made available within a reasonable telemetry band. When this is the case, a multiplexing technique can be developed that is well within the state-of-the-art of communication technology.

The advanced technology required here is concerned with finding a best mix between automation and manual assistance for particular processes. Both analytical and experimental techniques appear to be needed.

6.2.2 Automated Materials Sample Handling and Storage Apparatus

Automation in this context can be used for two different purposes. In one case, it could contribute to reducing the size, and probably weight, of the sample handling and storage system. This becomes important with MEC because of the large number of samples that is contemplated and because there will be a variety of preferred sizes among the samples. Present sample handling schemes use indexed positions for each sample and a simple mechanism goes to a particular position and moves that sample from the designated spot to the processor and returns it. The minimum size sample system would accrue by having the samples stored together in a relationship that does minimize storage volume for that set of samples. Another flight set of samples would have a different relationship and system size. This method requires, however, an adaptable transport mechanism, which involves flexible position indexing and gripping, handling and transporting of samples. New technology for this case requires modeling of the search and recognition function, development of special sensors (visual or tactile) and development of flexible gripping and transporting mechanisms.

The other case involves provision for possible failures in the storage and transfer system. As this system is largely mechanical, the provision of redundancy in major parts is impractical. Achieving reliability in the presence of such single point failure modes is not a new technology. Rather, conservative design and extensive testing have been used successfully in most space projects. The nature of many MPS experiment samples, however, precludes assuring their failure free movements to the processor and return through use of these techniques. Some failure modes could jam the entire sample movement mechanism, make a processor unavailable, or temporarily block sample transport and so waste a processor cycle.

New technology for this case should start with a failure mode and effects analysis of candidate sample movement and storage systems using the best understanding available on necessary system configurations. The next step would be development of sensing systems for detection of higher probability failure modes and provision for appropriate responses in the handling system.

6.2.3 Adaptive, Intelligent Avionics Systems

Within specific materials processors, there exist a number of opportunities to optimize scientific return through use of machine intelligence (computer control and robotics). Relieving dependence on the "man-in-the loop" could also lead to major cost savings.

Using machine intelligence in the MEC to optimize the overall payloads and subsystems operations is complex because of the number of levels in the decision hierarcy.

The objective of this development would be to enhance the process going on within the payload to: increase the productivity of all the MEC payloads on a given flight, reduce the cost of MEC missions by elimination of excessive telemetry/stored image data, and lower MEC mission cost by reducing the amount of manpower/equipment for ground control.

We know that NASA is very interested in the automation of materials processing (both ground and space). They are convinced that in the long term, extra-terrestrial materials will have to be used in the performance of some future space missions. Use of these materials will require development of highly automated processing systems. Ideally, if replication technology could be perfected to the point that systems with self replication capability are developed, an extra-terrestrial base could be established. The MEC project seems like a good place to start this work. This base could grow with time.

On the all-up MEC, we have the challenge to perform successful materials processing on long duration, multi-payload, multi-discipline, multi-mode missions. Dynamic behavior of complex MEC subsystems must be accounted for and controlled by "smart" sensors and mechanisms, operating remotely and automatically.

As long as detailed process control is kept in the payloads, near term needs for new technology in the MEC avionics systems are minimized. These systems should, however, make use of the most up-to-date fault tolerant designs that are appropriate to the MEC mission duration and maintenance modes.

7.0 RECOMMENDED AREAS OF FUTURE STUDY

The following work is suggested to provide a firm basis for starting the MEC Phase B study.

7.1 MEC DESIGN

Selection and further definition of the preferred MEC concept depends on concurrent development of MEC payload designs and operating profiles. In this MEC design study, a standard payload envelope and interface concept was adopted which allows flexibility in payload accommodation and convenient access for payload integration and interchange on the ground and payload servicing on orbit.

For similar reasons, the initial and all-up MEC design concepts emphasized payload autonomy rather than centralized MEC payload support functions. Confirmation of this design approach, and its assessment as the most cost effective path to system development/integration, is required as payload design activities progress and additional data on payload operations and interface requirements become available.

7.2 MEC PAYLOADS

Development of automated MPS payloads to be flown on MEC will be a gradual, evolutionary process. Prior flight experience of Materials Experiment Assembly (MEA) packages and of Spacelab MPS payloads will be available on most processes to be included in subsequent MEC missions. Four to six experiment packages/payloads currently in advanced development fall into this class. Others still require extensive definition, breadboarding and development.

The impact of projected payload characteristics and requirements on MEC design and operations must be taken into account on a timely basis. The concept of "standardized" MEC payload accommodation provisions that were adopted, largely to fill a gap in current knowledge of specific payload design requirements, should be affirmed or modified as necessary, at the earliest time, to avoid a MEC development that would unnecessarily restrict the growth of MPS payload support capabilities or require substantial future MEC design changes.

7.3 AUTOMATION

Transition from ground-based laboratory processes and Shuttle-based MPS experiments to fully automated payload operations constitutes the single, most challenging technology advance involved in bringing about a successful, practical, reliable and cost-effective MEC program. Evolution to fully automated operations without heavy ground-based monitoring and intervention will be required as the growth of MPS/MEC activities progresses from initial R&D missions to full commercial exploitation. Further study and breadboarding is suggested. Increased reliance on machine intelligence, which will minimize cumbersome and costly ground facility/human operator intervention and control, is expected to take place as the results of NASA's current thrust in developing this technology. In this respect, MEC will provide an effective and convenient transition path, with less than critical dependence on fully automated payload operations, until this new technology is matured.

7.4 ON-ORBIT SERVICING

The other facet of an orderly transition to fully automated payload operations on MEC is provided by planned, periodic on-orbit servicing operations being part of the MEC mission scenario. This will provide the opportunity for replacement or repair, if necessary, of payload units that fail to perform satisfactorily in the fully automated processing mode. The capability of early hands-on correction of such malfunctions on-orbit will reduce the risk inherent in committing sophisticated new payload equipment to extended missions in the early stages of the MEC program. The MEC project will benefit by additional study in this area.

On-orbit servicing, like other MEC mission phases requiring repeated Orbiter/Power System rendezvous and docking, will involve intricate, crew supported Orbiter operations that will only gradually evolve into routine activities. This aspect of the MEC mission does not require novel technology, per se, but involves a build-up of experience by Shuttle flight and ground crews. Principal concerns, regarding MEC design and mission planning, are an awareness of the inherent complexity of these orbital operations, a practical design approach that emphasizes simplicity and reliability, especially in interface implementation and systematic elimination of safety risks involved in MEC/payload manipulation by Shuttle crewman.

8.0 CONCLUDING REMARKS

The Materials Experiment Carrier is needed to advance space processing toward a fuller, more effective and economical utilization of the space environment, starting with a broadened research flight program and thrusting to full scale commercial applications.

In filling this need, MEC will be a principal user of the Space Platform in the free-flying mode, requiring a very high percentage of available Space Platform resources. Thus MEC will have a significant impact on the Space Platform's design and mission planning.

Further definition of the selected MEC design concept will depend on concurrent development of prospective MEC payload designs and operating profiles. In this Phase A MEC design study, standardized payload envelopes and MEC-to-payload interfaces were adopted. This allowed flexibility in payload accommodation and provided convenient access for payload integration and interchange on the ground and payload servicing on orbit.

For similar reasons, our selected MEC design concept emphasized payload autonomy rather than centralized MEC payload support functions. Confirmation of this design concept, and its assessment as the most cost effective approach to system development/integration, will be required as payload design activities progress and additional data on payload operations and interface requirements become available.

The initial MEC is an extension of the NASA/MSFC advanced MEA (MEA-C) spoked disc structure, subsystems, and payload elements. This, we conclude, is a technically feasible and cost saving way of evolving to the initial MEC. Here again, economy of technology utilization and application of hardware development were important factors in generating the all-up MEC configuration and its subsystems.

No major advances in spacecraft and subsystem technology will be required in achieving early MEC missions, starting in the 1987 time frame. However, reliance on ground based MEC process monitoring and control to augment autonomous payload operations can be reduced as advances in automated payload design and machine intelligence lead to more sophisticated and more autonomous flight systems.

Along with this trend, it is expected that MEC users will develop increased confidence in the ability of the system to detect, diagnose and, if necessary, correct anomalies in sample processing, without much supervision and assistance by ground based control.

The initial MEC concept, described in this study, can be developed and prepared for first flight in about 48 months. As more is known about the MEC design (Phase B), MEC payloads, and Space Platform implementation planning, this 48 months might be reduced.

Finally, it appears that six issues dominate the thinking and planning on the MEC project. They are listed below. Some relate to technology and engineering; most depend on NASA programmatic decisions; they all deserve near-term attention.

MEC PROJECT KEY ISSUES

1.	Project Costs	Goals for the initial MEC capability will certainly reflect NASA funding constraints.
2.	MEC Payloads	Type, number, dates of readiness for flight, envelope and requirements.
3.	MEC Growth	Extent to which initial MEC design can realistically evolve from MEA-C and then effectively grow to all-up MEC.
4.	Operations Costs	Transportation, logistical, payload integration, refurbishment and orbital operations costs could impact MEC utilization more than MEC design and development costs.
5.	MEC Users	MEC as a carrier for participants other than NASA. These could come from the private sector (commercial), international, and DOD sources.
6.	Space Platform Interfaces	Extent to which SP resources can be allocated to MEC, assuming multiple payloads attached to the SP.